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1900

A paper read at the 17th General Meeting of the American Institute of Electrical Engineers, Philadelphia, May 18th, 1900. President Hering in the Chair.

THE USE OF ALUMINIUM LINE WIRE AND SOME CONSTANTS FOR TRANSMISSION LINES.

BY F. A. C. PERRINE AND F. G. BAUM.

Until the present time, discussions of the use of aluminium wire in line construction have been devoted to a consideration of the relative prices of copper and aluminium wires, the conductivity, tensile strength and other proportions of the aluminium wire being only considered as determining its relative price. During the past year the manufacturers of aluminium have demonstrated their ability to sell this wire at a price well below twice the price of copper per pound, and in consequence the new material has forced itself upon our notice and has demanded that we consider carefully all of its properties independent of any consideration of price. Having recently been forced into the purchase of a considerable amount of this wire by reason of the high price of copper and the low price of aluminium, the writers have made a careful study of the wire supplied, and now present the results obtained in hope that they may be of service to other engineers.

Some of these results have already been published,[1] but in these publications there have been so many misprints that it seems advisable to present the whole matter anew. The line for which this wire was purchased is about forty-three miles in length, and the country through which it runs varies in elevation from about one hundred feet above the sea level to at least two thousand feet; one-half lying in almost a straight line through

1. Tests and Calculations on a Forty Mile Aluminium Transmission Line. F. A. C. Perrine, Pacific Coast Transmission Association.

a country almost level, while the remainder is over the mountains, through which the line runs almost straight, surmounting high hills and descending into deep gulches. In some cases the lengths of the poles were proportioned to decrease the vertical line deflection, but as an accurate preliminary survey was not available, much less grading of poles was possible than would have been desirable. This defect in pole setting was largely counteracted in the wire stringing by the drawing of a number of spans at one time, so that at depressions and elevations there was very little up or down strain put on the wire when it was tied to the insulators. The standard pole used was of square sawn redwood, thirty feet in length, seven inches square at the top, and tapering to twelve inches square at the butt, or about eleven inches at the ground line five feet above the butt. Each pole was gained for three cross-arms 20½ inches on centers, the gains being cut ¾ inch deep, into which the cross-arms were bolted by single ⅝ inch through bolts. The arms themselves were 4x4 inch Oregon pine bored for two pins each, the top and bottom arms being three feet in length and the center arm four feet. The wires on this system of construction are arranged in a hexagon, each side being 24 inches in length.

This system of construction presents some advantages for three-phase working at high voltages for long lines, especially where the two sets of circuit are to be operated from the same bus bars. If both of the wires on each arm are at the same potential, the arrangement of each circuit is that of an equilateral triangle, each side being 41 inches, while the minimum distance for leakage between any two wires of different phases is 36 inches of cross-arm and 20 inches of pole, while the length of the longest arm necessary is much less than that in any other system of construction; the pole head is symmetrically loaded, and for these reasons the pole construction is exceptionally stable under all stresses.

The insulators used were a flat topped glass, triple petticoat type, about five inches in height and seven inches in diameter, with a wire groove of about .35 inches radius. The insulators are supported by eucalyptus pins of a length to give a distance of four inches between the bottom of the insulator petticoat and the cross-arm, eucalyptus wood having been used on account both of its availability in California for a special pin, and on account of its great strength, which is of extreme importance

in the construction of pins of such length.[1] For further insulation and preservation, the cross-arms used were creosoted by a treatment in which the timber was at first dried carefully and then injected with ten pounds of dead oil of coal tar to the cubic foot, an operation requiring approximately thirteen hours for its completion, while the pins were boiled at a temperature of about 225° F. for about eight hours in a compound of coal tar and asphaltum, a treatment which gave a better external surface than the creosote. This latter coating did not penetrate the wood materially, but after experimenting extensively with this wood at temperatures up to 225° F. and pressures up to 160 pounds per square inch without effecting any appreciable penetration of this wood, either with creosote or other extremely fluid materials, all idea of the use of a penetrating compound was abandoned, and an endeavor made to obtain a coating which would provide the most complete external protection.

On this line as erected, the arms were braced by a bent angle iron brace, but this precaution seems now to be entirely unnecessary, and a subsequent line belonging to the Yuba Power Co., erected on much the same plan, is not braced at all. For arms of over five feet in length a brace is certainly advantageous, though it is the opinion of the writers that for high potential service the braces should be of wood mortised into the cross-arms and nailed to the pole face.

The above complete physical details of the construction are unnecessary for the discussion of aluminium line wire, though it is believed that its stability when erected depends upon a careful study of all such conditions.

The line as erected carried only four wires arranged on the top and bottom cross-arms, thus taking their location at the corners of a rectangle 24″ on the short side and 41″ on the long side. This arrangement was adopted for the purpose of making temporary use of some two-phase machinery which was in place and underloaded, allowing certain new customers to be taken on quite a year in advance of the contemplated completion of a three-phase plant for which the pole line was really designed.

It was at first feared that this arrangement of the wires would result in inductive disturbances between the phases, as the wires

1. Tests of a considerable number of pins made of eucalyptus, oak and locust show that the eucalyptus has about 20 per cent. more strength than locust and 30 per cent. more than oak.

took their positions in the diagonally opposite corners of a rectangle, in place of the corners of a square, as is necessary for complete absence of mutual induction, but the anticipated trouble was not found. Careful measurements were made with one phase short-circuited and the other carrying about 20 amperes with a periodicity of 60 cycles per second, both with a Weston 75-volt voltmeter and a Rowland electro-dynamometer, with the result that no deflection was observable on the voltmeter, while the current read on the electro-dynamometer amounted to only about .001 ampere, the resistance of the dynamometer being 25 ohms and of the line 90 ohms. Only one additional question of installation needs attention, which is the presence on the tops of the poles of a barbed wire stapled to the wood of the pole and grounded at every fourth pole by a galvanized iron wire leading down along the pole and soldered to an iron plate 18 inches square and $\frac{1}{8}$ inch thick, set in the pole hole immediately under the foot of the pole itself. This wire was intended as a lightning guard, and it has apparently done very effective service in discharging the line in all weather.

The wire used was intended to be equal to No. 3 B and S copper wire in its electrical resistance, and the manufacturers were required to furnish this conductivity in a wire not weighing more than 420 pounds per mile. All the wire supplied was carefully inspected by Dr. A. E. Kennelly, and his reports give the following averages for the total quantity:—

Diameter	293.9 mils
Wt. per mile	419.4 lbs.
Resistance per mil foot	17.6 ohms at 25° C.
Resistance per mile at 25° C.	1.00773 ohms
Conductivity compared with copper	59.9% by dimension
Tensile strength of wire	1549 lbs.
No. of twists in six inches for fracture	17.9
Tensile strength per square inch	32898

Comparing this with copper it is seen that this wire is approximately the same as copper in the following sizes:—

Size of aluminium wire	= No. 1 B & S copper
Resistance of " "	= No. 3 " "
Tensile strength " "	= No. 5 " "
Weight of " "	= No. 6 " "

Therefore on the basis of the same conductivity the aluminium compares with copper as follows:—

Diameter for the same conductivity			1.27	times	copper
Area	"	"	1.64	"	"
Tensile strength	"	"	.629	"	"
Weight	"	"	.501	"	"

The mechanical properties of this wire present some well marked characteristics. In the first place, the number of twists necessary for fracture varies considerably, although the ductility test of wrapping six times around its own diameter, unwrapping and wrapping again is well sustained. This irregularity in the twisting test is generally a mark of impurity in wire, but we know so little as yet of the exact characteristics of aluminium in particular, and the twisting test is in general so unreliable that it is unsafe to base any exact statement on this one test, particularly as the same after erection proved reliable. In carefully performing the test for tensile strength no exact point could be assigned for the elastic limit, as the metal seemed to take a permanent set almost from the first, but at a stress of from 14,500 pounds to 17,000 pounds per square inch, there is a marked increase in the permanent set which indicates that the safe working load lies somewhere in this region. In this the characteristics of the aluminium do not differ materially from those of copper or other similar metals, and while this is a disadvantage it is not a singularity.

The fact that the wire will permanently elongate if seriously strained, makes it necessary to use the utmost care in the erection of lines, and also the known high coefficient of expansion with temperature changes taken in conjunction with this property renders care in line stringing especially important and difficult.

For the purpose of ascertaining exactly what were the changes with temperature that might be anticipated, the Pittsburg Reduction Company undertook a series of experiments by means of the observation of 200 foot spans of wire at temperatures varying between 6° F. and 55° F., and at the same time the authors carried on a similar series of experiments on a 150-foot span at the Leland Stanford, Jr. University in which the temperatures varied between 20° F. and 80° F. From the results of these experiments a coefficient of expansion with temperature was obtained, which was used in calculating sets of tables for the instruction of the line foreman which gave the tensions and deflections at the different temperatures encountered. These tables were calculated by use of the ordinary approximate formula for the

tensions and deflections of a suspended wire, and the method used for obtaining the coefficient of temperature expansion removes the usual objection to the formulæ that they do not take into account the elasticity of the wire itself, which produces serious errors if an attempt be made to use the true coefficient of linear expansion by changes of temperature. In fact, the coefficient of linear expansion obtained from these experiments is less than one-half the value of the true coefficient of linear temperature expansion, but its use is justified by the fact that the tables as calculated have been frequently verified experimentally, both at the testing stations and in the field, while the line was being strung. A comparison of the calculated and observed results obtained by the Pittsburg Reduction Co. is given below in Table No. I. As a result of these tests the above-mentioned company have issued a table of deflection tensions and temperatures which is given in Table No. II.

TABLE I.

COMPARISON OF OBSERVED AND CALCULATED DEFLECTIONS OF ALUMINUM WIRE.

Temp.	C	D	G	H
0°	21 20⅜	20¾ 20⅜	20⅜ 20⅜	20¾ 20⅜
10°	24⅛ 24⅞	24 24⅞	24 24⅞	24 24⅞
20°	28 28¾	26⅝ 28¾	26⅞ 28¾	27 28¾
30°	31⅜ 31⅞	30⅛ 31⅞	30⅜ 31⅞	30⅜ 31⅞
40°	34⅝ 35¼	34⅛ 35¼	34⅝ 35¼	34⅞ 35¼
50°	37⅞ 38¼	37⅛ 38¼	37⅞ 38¼	37⅛ 38¼
60°	41⅛ 40¾	40¾ 40¾	40¾ 40¾	41 40¾

C = No. 2 × B Aluminium wire
D = No. 2 Pure " "
G = No. 10 × B " "
H = No. 10 Pure " "

February 4th, 1899.

Upper figure is the Observed Deflection.
Lower " " " Calculated "

From the results of the experiments made at the Stanford University a table was calculated in accordance with which the line under discussion was strung. Table No. III.

Attention must be called to the fact that while the minimum temperature given in the table used in California is + 20° F.,

TABLE II.

Table of Deflections and Tensions for Aluminum Wire.

X = Deflection in inches at centre of span. S = Factor which, multiply by weight of foot of wire to obtain tension. Maximum Load = 15,000 per square inch.

	t = −20°		−10°		0°		10°		20°		30°		40°		50°		60°		70°		80°		90°	
Span	S	X	S	X	S	X	S	X	S	X	S	X	S	X	S	X	S	X	S	X	S	X	S	X
80	12940	3/8	1660	5 1/2	1176	8 1/8	961	10	833	11 1/8	781	12 1/8	680	14 1/8	630	15 1/4	589	16 1/8	555	17 1/8	527	18 1/4	501	19 1/8
100	12940	1 1/2	2083	7 1/4	1470	10 1/2	1202	12 1/2	1042	14 1/8	933	16	869	17 1/2	7(8	19	735	20 1/8	695	21 1/2	658	22 3/4	628	23 7/8
120	12940	1 1/8	2500	8 1/8	1768	12 1/2	1400	15 1/8	1251	17 1/2	1120	19 1/2	1022	21 1/2	946	22 7/8	885	24 1/2	835	25 7/8	792	27 1/2	755	28 3/4
150	12940	2 1/8	3038	11 1/8	2540	14 1/2	1788	18 7/8	1552	21 1/2	1390	24	1265	26 1/8	1177	28 1/8	1060	30 1/8	1039	32 1/2	987	34 1/2	941	35 1/2
175	12940	3 1/2	3643	12 1/8	2576	17 3/8	2104	21 1/2	1822	25 1/2	1630	28 1/2	1488	30 1/2	1377	33 1/8	1279	35 7/8	1215	37 3/4	1152	39 7/8	1099	41 1/2
200	12940	4 1/8	4206	14 1/2	2947	20 3/8	2403	24 7/8	2084	28 1/2	1930	31 1/2	1672	35 1/2	1574	38 1/2	1473	40 1/2	1393	43	1316	45 1/2	1256	47 1/2

TABLE III.

Tension and Deflection Tables for Line Construction.

T = pounds. h = inches. t = temp. of wire. Oct. 17, 1898. Tension and deflections for No. 1 Aluminum wire. (Wt. 420 lbs. per mile.)

	t = 20°		30°		40°		50°		60°		70°		80°		90°		100°		110°		120°	
Span	T	h	T	h	T	h	T	h	T	h	T	h	T	h	T	h	T	h	T	h	T	h
80	1025	3/8	149	5 1/2	106	7 3/8	84	9 1/2	77	10 1/4	65	11 3/8	59	12 3/8	55	13 3/8	51	14 3/8	48	15 1/2	45	17
132	1025	1 1/2	220	8 3/4	166	13 1/2	138	15	119	17 3/8	107	19 1/4	97	21 1/8	91	23	81	24 1/8	80	26 1/4	73	27 1/2
200	1025	4 1/8	427	14 1/2	311	19 1/2	258	23 1/2	221	26 1/2	200	30	184	32 1/2	170	35 1/2	157	37 1/2	150	39 1/2	143	41 1/2

that given by the Pittsburg Reduction Co. is = —20° F. These different minimum temperatures are made necessary by the conditions under which the wires are to be strung, and they indicate merely the starting points of the tables; counting from this point it is seen the maximum difference in deflection for the two tables is $4\frac{3}{4}$ inches for the 200-foot span at a temperature rise of 100 degrees above the minimum. While this difference in deflection is not beyond the errors in the thermometer and deflection observations in the field, it is the belief of the writer that Table No. II is the more reliable on account of the fact that it was deduced from a larger series of observations made under the more favorable circumstances.

A copy of Table No. III together with the following instructions was issued to the line foreman, who was also provided with a thermometer, a dynamometer and a pair of targets for measuring the deflections.

Instructions to line foreman in stringing wires :—

1. All spans are to be strung with deflections and tensions as specified in table.

2. Up and down hill spans to be sprung to correspond with level spans. In case level spans cannot be used, then employ dynamometer, and ease all wires over cross-arms.

3. All ties are to be made at one time by signal.

4. All ties are to be made by crossing wires around insulator serving three times around wire, and twisting behind insulators; the ends of the tie-wires are not to be cut, but bent back toward insulators.

5. Tie all wires on the outside of the insulators, except at corners where all are to be tied so that the strain is against the insulator.

6. Joints are to be made by means of sleeves twisted two and a half times, the ends of the wires being given one turn by hand around the wire. No tools are used, except in twisting the sleeves and cutting off the ends of the wires. Before inserting the wire in the sleeve, the ends of the wire must be roughened by draw filing.

7. Barbed wire is to be laid along the roofs of the poles and held by three staples driven in tight, but without kinking the wire. Ground wires are to be soldered to the barbed wire and at the bottom of the pole to the wire leading from the ground plate. All soldering acids must be carefully washed away after the soldering is done.

8. Beginning between poles one and two, all wires are to be barreled by shifting one pin, and same to be repeated between poles 21 and 22 and 41 and 42, and so on. Barreling always in the same direction of twist every twenty poles. A record must be kept of the location of every wire and every pole.

General Caution.—The greatest care must at all times be taken against kinking or scarring the wire; wherever the wire is accidentally kinked or scarred it must be cut and spliced.

The targets mentioned above consisted of light sheet iron strips about two feet long and two inches wide, with an aluminium hoop bent into an eye at the top, by means of which they could be hung from the line wire. These targets were painted in three or four colors, with bands one inch wide. In use, the captain of the linemen would hang his target on the wire to which a man on the next pole had also hung a target; then, as the wire was being pulled into place, he would sight from a band on his target to the same band on the adjacent target, and when the wire came into line with these two bands the signal would be given for all the linemen to tie at once. As a result of this method of stringing, an exceedingly uniform line and one strong in accordance with the temperature was obtained.

One of the most serious problems in connection with the use of aluminium is in the choice of a proper joint. This metal is so highly electro-positive that it is unsafe to expose it to the elements in contact with any other material, as electrolytic corrosion is almost sure to follow such construction. Many of the failures which have been reported of this metal have been due to a neglect of this fact; as notably in the case of the plates on the yacht *Defender*, where the plates have been corroded at the contact with the bronze rivets used in fastening them to the frame. Whenever this metal is soldered or used in contact with any other metal, the joint should be thoroughly waterproofed to prevent such action. After discussing many joints, it was finally determined to abandon any attempt to solder or clamp the wire in any manner, and the joints were made by slipping the ends of the wire into an oval aluminium tube about nine inches long, which was then twisted with a pair of clamps similar to those employed in twisting the McIntire connector. After twisting the tube a turn was taken by hand of the loose ends and the wire cut off close. The joint produced proved practically equal to the original wire in both tensile strength and electrical conductivity.

This wire was erected during the winter of 1898–99, which was an unusually open winter over the whole State of California, allowing practically continuous construction work, though the temperature varies all the way from about 30° F. to 80° F. at times when the wire was being strung. After it was finally erected it remained about three months on the poles before the machinery was delivered and put in place. During the first month of that time three breaks occurred which were all apparently due to flaws in the material; but after these breaks were repaired the line wire gave absolutely no trouble whatever, though various accidents occurred to other parts of the construction. Many insulators were shot at and broken, bale wire and bale rope was thrown over the line, a twig short-circuited one phase and fell down burned, a large bird was killed by contact with the wires, and finally several porcelain insulators with porcelain pins were broken off and hung suspended by the wire. In January and February of the present year this whole line was taken down to give place to a much heavier one of the same material, an opportunity for such a total change having been found after the total destruction of the power-house by fire last November.

During the past two years other lines of aluminium wire have been erected on the Pacific coast, all but one of which have given a considerable amount of trouble from causes that are not entirely apparent.

One line in Nevada County, erected at about the same time as that we have been describing, and for which the wire was of practically the same lot, has given no trouble whatever.

The power transmission lines of aluminium wire about Seattle have broken a few times, but have not given serious trouble. The breaks in this line, so far as the writers have been informed, seem to have been due to not allowing enough sag at the higher temperatures, and a consequent overstraining of the wire in cold weather.

The most serious difficulties have been encountered by the telephone company in Washington and Oregon and by the Yuba Power Co. In all of these cases it seemed almost impossible to keep the wires on the poles in certain sections, and in these sections the lines have been finally taken down and replaced by other wire of either copper or aluminium. The writers have examined many breaks from these lines, and would judge, from the

appearance of the fracture, that the cause, whatever it may be, was similar. In those breaks there are many small flaws, but by far the greatest majority are clear, sharp fractures, with but a slight reduction of area, and that entirely on one side, a break very characteristic of improperly mixed and brittle alloys. Partially from the appearance of the fracture and partially from the facts that the breaks occur only in certain sections of the line, the writers are of the opinion that this trouble is due to the presence of impurities in the material. This view is strengthened by the fact that when measurements were made on the line of the Yuba Power Co., the resistance of the whole line was found to be 10 per cent. greater than it should have been if it were made of the quality of material described in the earlier part of this paper. Furthermore, in one-half of this line there were no breaks at all due to defects in the wire itself.

As a general conclusion, it is the opinion of the writers that aluminium can be safely used in place of copper where the proper precautions are taken in inspecting the wire before it is erected, and in erecting it with due consideration of its peculiar properties of low and indefinite elastic limit, high coefficient of temperature expansion and active electrolytic power.

Indicating our faith in this opinion, it may be noted that for the new line soon to be erected an aluminium strand $\frac{3}{4}$ inch in diameter has been ordered. This strand will be spliced with aluminium sleeves, and in the whole construction about one million pounds of aluminium will be employed.

Experimental and Mathematical Determination of Line Constants.

Opportunity was given to test the line described above and also another aluminium line 62 miles in length, No. 4 B. and S. wire. These lines were tested for capacity, self-induction, mutual induction, ohmic resistance and insulation.

As there has been some difference of opinion among electrical engineers as to the charging current or capacity current of a three-phase line, great care was taken to accurately determine the capacity of a line when arranged, as is usual in practice, with the wires on the corners of an equilateral triangle. If the line capacity may be considered as connected between the wires Δ, the charging current in one wire would be $\sqrt{3}$ times the charging current of a single-phase line for the same voltage and

distance between wires. On the other hand, if the line capacity is star connected, the charging current of one wire would be $\frac{2}{\sqrt{3}}$ times the charging current of a single-phase line for the same voltage and distance between wires. To determine which of the above is the correct assumption, it was only necessary to charge the three wires with three-phase potential and measure the current in one wire, then disconnect one wire from the potential source and read the ammeter again. All the measurements indicated that the line capacity is to be considered as star connected.

The method used to determine the line capacity was to insulate one end of the line and to charge the line with three-phase potential from the other end. To measure the potential applied, a Weston 150-volt voltmeter, which was checked before and after the experiments, was used. To measure the current a special Rowland electro-dynamometer was used. The instrument was calibrated and frequently checked in the position used, by sending a current through it and a known non-inductive resistance by a known potential difference. The leakage current over the insulators could be neglected. For convenience, safety, and to eliminate errors, a low potential, 130 to 200 volts, was applied to the line and the ammeter connected directly in series with one line wire. The results obtained for the capacity of a three-phase line experimentally agree with those obtained by calculation. No disagreement with the conclusion has yet come to our notice, although the charging current has been subsequently observed with voltages as high as 25,000, and no disagreement is expected in the line at present being erected; the potential of the line is to be above 40,000 volts between wires, the wires being $\frac{3}{4}''$ aluminium cables with 42″ between centers.

The method used in making these calculations—which is here given—is believed to have an advantage of simplicity over the method due to Oliver Heaviside, now generally used for calculating the electro-static capacity of transmission lines. It will be found to give a solution for all cases found in practice with little labor.

In calculating the capacity of a condenser, the plates are assumed charged with equal and opposite quantities of electricity and the potential difference between the plates is calculated;

the capacity of the condenser being defined as the ratio of the quantity of electricity on one of the plates to the difference of potential between them.

Take, first, the simple case of two wires suspended in free space, Fig. 1. Charge wires with $+Q$ and $-Q$ units of electricity per unit of length of line. The potential difference between wire A and B may be found by moving a unit quantity of electricity from the surface of A to the surface of B, or, since there is a plane of zero potential midway between A and B, we may move the unit charge from O to the surface of B. This will give the capacity between B and the mid-plane.

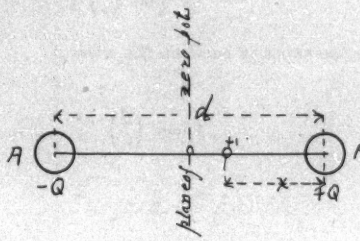

FIG. 1.

The force acting on the unit quantity at the distance x from B is

$$F = -\frac{2Q}{x} - \frac{2Q}{d-x} \qquad (1)$$

Multiply by $-dx$ and integrate between the limits $x = \frac{d}{2}$ and $x = r$ (r = radius of wire).

We get

$$V = \left[2Q \log x\right]_r^{\frac{d}{2}} - \left[2Q \log (d-x)\right]_r^{\frac{d}{2}}$$

$$= 2Q\left(\frac{d}{2}\right) - 2Q \log (r) - 2Q \log\left(\frac{d}{2}\right) + 2Q \log (d-r)$$

$$= 2Q \log\left(\frac{d-r}{r}\right)$$

Or, since for ærial lines r is small in comparison with d, we have $V = 2Q \log \left(\frac{d}{r}\right)$, and the capacity in electro-static units between A and the mid-plane per unit length of line is

$$C = \frac{1}{2 \log_e \left(\frac{d}{r}\right)} \tag{3}$$

The total potential between the two wires is

$$V = 4Q \log_e \left(\frac{d}{r}\right)$$

and therefore the capacity between the wires

$$C_{ab} = \frac{1}{4 \log_e \left(\frac{d}{r}\right)}. \tag{4}$$

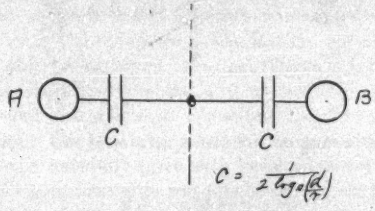

FIG. 2.

It will simplify matters some when we come to multiphase circuits to consider the capacity C_{ab} between the two wires as made up of two capacities, C equation (3), connected in series from A to B, as in Fig. 2.

From the above proof it follows that in calculating the capacity of different systems the following general proposition may be made regarding the work done in moving unit quantity of electricity from one point of an electrostatic field to another, the field being due to a charged wire, the wire being considered infinite in length:

The work done in moving unit quantity of electricity from one point of an electric field to another against the force due to

a charged wire is equal to twice the quantity of electricity on the wire times the logarithm of the ratio of the initial to the final distance of the unit charge from the wire. If there are several wires in the field the algebraic sum of all the terms formed as above will give the work; the sign of each term is

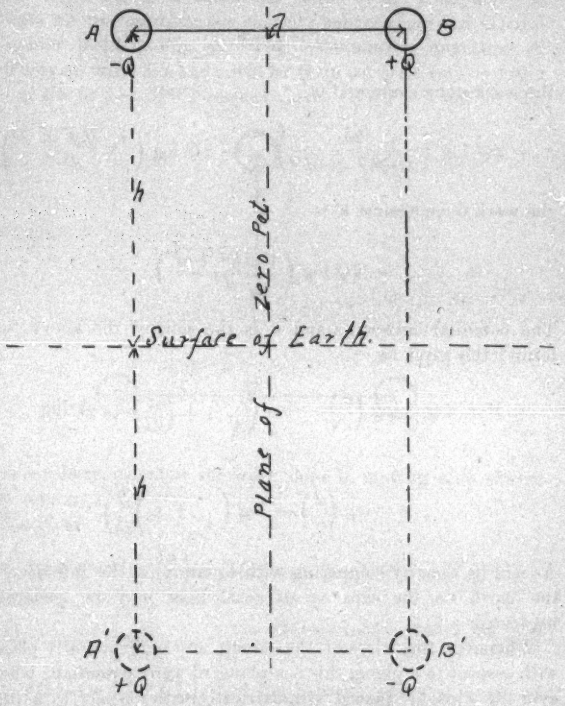

FIG. 3.

determined by the sign of the quantity of electricity on the wire in question.

As an illustration of the above let us find the effect of the earth on the capacity of two wires distanced h above its surface, Fig. 3. Move the unit quantity of electricity from the surface of A to B.

The work done against the force due to A is

$$-2Q \log\left(\frac{r}{d}\right) = +2Q \log\left(\frac{d}{r}\right);^*$$

the work done against B is

$$+2Q \log \frac{d}{r};$$

the work done against A^1 is

$$+2Q \log\left(\frac{2h}{\sqrt{(2h)^2+(d)^2}}\right) = -2Q \log\left(\frac{\sqrt{(2h)^2+d^2}}{d^2}\right);$$

the work done against B^1 is

$$-2Q \log\left(\frac{\sqrt{(2h)^2+d^2}}{d^2}\right)$$

The potential between A and B is the sum of the above four terms; this gives us

$$V = 4Q\left[\log\left(\frac{d}{r}\right) - \log\left(\sqrt{1+\left(\frac{d}{2h}\right)^2}\right]\right., \text{ giving}$$

$$C = \frac{1}{4\left[\log\left(\frac{d}{r}\right) - \log\left(\sqrt{1+\left(\frac{d}{2h}\right)^2}\right)\right.} \qquad (5)$$

As will be seen by comparing with equation (4) the influence of the earth on the capacity of ærial lines may be generally neglected.

Whenever the wires of the circuit are symmetrically placed with respect to a plane, this is a plane of zero potential; whenever the wires are placed symmetrically with respect to a line, this will be a line of zero potential. It is assumed in the above that there are no other wires very near the wires of the

* This should be $-2Q \log_e\left(\frac{d-r}{r}\right)$, but r may always be neglected in comparison with d for ærial lines. This assumption is made throughout the paper.

circuit. In such cases—practically all transmission lines—it is usually simpler to calculate the capacity between one wire and the plane of zero potential or between one wire and the line of zero potential.

Three-phase transmission lines are usually arranged with the wires on the corners of an equilateral triangle, this arrangement gives a line of zero potential at the center of the triangle. For this case we may calculate the capacity between one wire (A) and the center point O, Fig. 4. The instantaneous quantities of electricity on wires A, B and C will be $Q \sin \omega t$, $Q \sin (\omega t - 120°)$ and $Q \sin (\omega t - 240°)$ respectively. With the aid of the

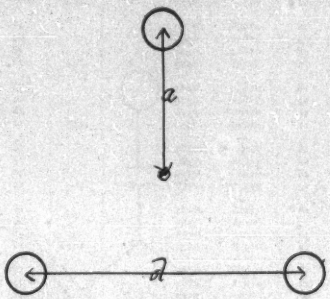

FIG. 4.

above corollary, calculate the work done in moving unit charge from O to A.

This gives

$$V = 2Q \sin \omega t \log \left(\frac{a}{r}\right) + 2Q \sin (\omega t - 120°) \log \left(\frac{a}{d}\right) + 2Q \sin (\omega t - 240°) \log \left(\frac{a}{d}\right)$$

$$= 2Q \sin \omega t \log \left(\frac{d}{r}\right);$$ and the capacity per unit length of line is

$$C = \frac{1}{2 \log_e \left(\frac{d}{r}\right)};$$ the same result for B and C.

The result gives the capacity arranged as in Fig. 5, which agrees with experiment.

TABLE IV.

Capacity in Micro-Farads and Charg. Cur. per mile of circuit for three-phase system.

Line E.M.F.—10,000 volts. 60 P.P.S.

Size B. & S.	Diam. in inch.	Distance d in inch.	Capacity c M. F.	Charg. cur. in Amperes	Size B. & S.	Diam. in inch.	Distance d in inch.	Capacity c in M. F.	Charg. cur. in Amperes
0000	.46	12	.0226	.0492	4	.204	12	.01874	.0408
		18	.0204	.0447			18	.01726	.0377
		24	.01922	.0418			24	.01636	.0356
		48	.01474	.0364			48	.01452	.0317
000	.41	12	.0218	.0474	5	.182	12	.01830	.0399
		18	.01992	.0414			18	.01690	.0368
		24	.01876	.0408			24	.01602	.0349
		48	.01638	.0356			48	.01426	.0311
00	.365	12	.0214	.0465	6	.162	12	.01788	.0389
		18	.01946	.0423			18	.01654	.0360
		24	.01812	.0399			24	.01560	.0342
		48	.01604	.0349			48	.0140	.0305
0	.325	12	.02078	.0453	7	.144	12	.01746	.0389
		18	.01898	.0413			18	.01618	.0352
		24	.01642	.0379			24	.01538	.0335
		48	.01570	.0342			48	.01374	.0299
1	.289	12	.02022	.0440	8	.128	12	.01708	.0372
		18	.01952	.0403			18	.01586	.0341
		24	.01748	.0380			24	.01508	.0328
		48	.0154	.0337			48	.01350	.0294
2	.258	12	.01972	.0372	9	.114	12	.01660	.0364
		18	.01818	.0305			18	.01552	.0337
		24	.01710	.0372			24	.01478	.0317
		48	.01510	.0328			48	.01326	.0289
3	.229	12	.01938	.0421	10	.102	12	.01636	.0356
		18	.01766	.0385			18	.01522	.0329
		24	.01672	.0364			24	.01452	.0310
		48	.01480	.0322			48	.01304	.0284

Basis of Table.

$$C = \frac{1}{2 \log_e \left(\frac{d}{r}\right)},$$

in electro static units per cm. of circuit.

$$C = \frac{0.0776 \times L}{2 \log_{10} \left(\frac{d}{r}\right)},$$

in micro-farads bet. one wire and neutral point for L miles of circuit.

$$\text{Charg. cur per wire} = \frac{E \times C \times 2\pi \times f}{\sqrt{3} \times 10^6}$$

d = distance bet. wires, (inch).
r = radius of wire (inch).
L = length of circuit in miles.
E = E.M.F. bet. wires
f = cycles per sec.
C = cap. in M.F. bet. one wire and neutral pt.

Charg. cur. three-phase $= \frac{2}{\sqrt{3}}$ (= 15.5%) × charg. cur. sing. phase for same d, r. L, and E.

If the wires are arranged on a straight line and not transposed, the line of zero potential moves harmonically between the two points midway between the two outside wires. The capacities between any two of the wires may be found by the method given, the unit quantity being moved from the surface of one wire to the surface of the other. If the wires are transposed, the capacity of the line may be approximately determined by adding the capacities of the several sections. The capacity for any arrangement will not differ greatly from that given for the wires arranged as in Fig. 5. Table 4 has been prepared for convenience; the capacity in micro-farads and the charging current per mile with 10,000 volts between wires are given for a frequency of 60 P. P. S.

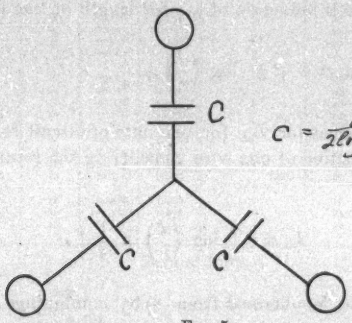

FIG. 5.

The self-induction of the line experimented upon was determined by short-circuiting the line at one end and measuring the current produced by a known potential. The observed result agreed with the calculated value.

The self-induction of one wire of a three-phase circuit arranged on the corners of an equilateral triangle is usually calculated by assuming the other two wires as a return at a distance D. To get the inductive drop between two wires, the self-inductions are combined geometrically. This is correct, but as no mathematical proof has come to our notice, one is here given:

The wires are arranged as in Fig. 4, the currents in A, B and C being $I \sin \omega t$, $I \sin (\omega t - 120°)$ and $I \sin (\omega t - 240°)$

respectively. The number of lines of force threading A B per unit length of line at time t is

$$N_{ab} = 2I \sin \omega t \log \left(\frac{d}{r}\right) + \frac{I \sin \omega t}{2} -$$

$$\left[2\, I \sin (\omega t - 120°) \log \left(\frac{d}{r}\right) + \frac{I \sin (\omega t - 120°)}{2}\right]$$

(Wire C has no effect on looop A B.)

$$= 2\sqrt{3}\left[\log \left(\frac{d}{r}\right) + \frac{1}{4}\right] I \sin \left(\omega t + \tan^{-1} \frac{1}{\sqrt{3}}\right);$$

giving for the self-induction of A B for length of line L

$$L_{ab} = 2\sqrt{3}\left[\log \left(\frac{d}{r}\right) + \frac{1}{4}\right] \times L. \qquad (7)$$

Table 5 gives values for L_{ab} for one mile of circuit for 66 P. F. S.

The self-induction of one wire considering the return at a distance d is

$$L_a = 2\left[\log \left(\frac{d}{r}\right) + \frac{1}{4}\right] \qquad (8)$$

Equation (7) may be obtained from (8) by combining L_a and L_b geometrically.

If the wires forming the circuit are arranged in a straight line and transposed, each wire taking the center pin for $\frac{1}{3}$ the distance, wire C will have no effect on the loop A B. Arranged in this way the wires A B will be apart distanced d for two-thirds of the length of the line and $2d$ for the remaining one-third. The self-induction of the loop A B is, then:

$$L_{ab} = 2\sqrt{3}\left\{\left[\log \left(\frac{d}{r}\right) + \frac{1}{4}\right]\frac{2}{3} L + \left[\log \left(\frac{2d}{r}\right) + \frac{1}{4}\right]\frac{L}{3}\right\} \qquad (9)$$

This shows that aside from the question of transposing there is some advantage in arranging the wires on the corners of an equilateral triangle.

TABLE V.

Inductance per mile of circuit for three-phase system. 60 P. P. S.

Size B. & S.	Diam. in inch.	Distance d in inch.	Self. Ind. L_{ab} Henrys.	Inductance $L_{ab} \times 2\pi \times 60$ Ohms.	Size B. & S.	Diam. in inch.	Distance d in inch.	Self. Ind. L_{ab} Henrys.	Inductance. $L_{ab} \times 2\pi \times 60$ Ohms.
0000	.46	12	.00234	0.884	4	.204	12	.00280	1.057
		18	.00256	.967			18	.00300	1.133
		24	.00270	1.015			24	.00315	1.189
		48	.00312	1.178			48	.00358	1.351
000	.41	12	.00241	.910	5	.182	12	.00286	1.080
		18	.00262	.989			18	.00307	1.159
		24	.00277	1.046			24	.00323	1.220
		48	.00318	1.201			48	.00356	1.344
00	.365	12	.00248	.937	6	.162	12	.00291	1.098
		18	.00269	1.016			18	.00313	1.182
		24	.00285	1.076			24	.00329	1.243
		48	.00330	1.246			48	.00369	1.393
0	.325	12	.00254	.959	7	.144	12	.00298	1.125
		18	.00276	1.042			18	.00310	1.204
		24	.00293	1.106			24	.00336	1.269
		48	.00331	1.250			48	.00377	1.423
1	.289	12	.00260	.983	8	.128	12	.00303	1.144
		18	.00281	1.061			18	.00325	1.227
		24	.00298	1.125			24	.00341	1.288
		48	.00338	1.276			48	.00384	1.450
2	.258	12	.00267	1.008	9	.114	12	.00310	1.171
		18	.00288	1.088			18	.00332	1.253
		24	.00304	1.148			24	.00348	1.314
		48	.00344	1.299			48	.00389	1.469
3	.229	12	.00274	1.035	10	.102	12	.00318	1.201
		18	.00294	1.110			18	.00340	1.284
		24	.00310	1.171			24	.00355	1.340
		48	.00351	1.335			48	.00396	1.495

Basis of Table.

$$L_{ab} = 2\sqrt{8}\left[\frac{\log\left(\frac{d}{r}\right)}{0.434} + \frac{1}{4}\right] = \text{self ind. in C. G. S. units for loop } a.\ b. \text{ (per. cm.)}$$

$$L_{ab} = 0.000558\left[2.303\ \log_{10}\left(\frac{d}{r}\right) + .25\right] L, \text{ in henrys.}$$

Inductive drop in loop $ab = L_{ab} \times 2\pi \times f \times I$.

d = dis. bet. wires (inch).

r = rad. of wire, "

L = length of circuit in miles.

f = cycles per sec.

I = current in one wire.

For self ind. of one wire divide L_{ab} by $\sqrt{8}$

Regulation of Transmission Lines.

The question of the regulation of the system for possible power factors is important. Knowing the probable power factor of the load the line-drop may be calculated, thus determining the amount

of regulation which must be allowed. If there are several sub-stations at different distances from the generating station to be supplied, the regulation to be allowed in each sub-station should be calculated. As the charging current of the line has an important bearing on the regulation of the system this question will be discussed.

At the present time there are two methods for determining the effect of the capacity current of a line on the voltage of the receiver. In the method most commonly used[1] the line capacity is assumed to be concentrated at one point, or for longer lines, the capacity is divided into several parts and these several capacities are connected across the line at various points. The pressures consumed over the line are then added geometrically to the receiver pressure. In the second method—involving hyperbolic functions—the algebraic results are worked out for distributed capacity. Both these methods are open to objection:

The first because for long lines—75 to 150 miles—it is quite laborious. The second method, while it is accurate and would be the only method to use if our transmission lines were several hundred miles in length, has the disadvantage that the equations come out in such form as to be practically meaningless to any but trained mathematicians. Most men do not like to use formulæ blindly: that is, formulæ which cannot be analyzed and each term given some physical meaning are not popular with practical men.

The method here given is a modification of the first mentioned, and will be found to give results, for distances up to 200 miles and possibly 300, as accurate as we could get by actual measurements on the completed line with the best instruments at present available for measuring alternating currents. Only one assumption is made that is not absolutely correct: The charging current per unit length of line is the same at all points of the line.

The error involved in this assumption can be very easily determined. The rise in voltage—with receiver circuit open—over a transmission line about 60 miles in length, and about 30″ between wires, is about one per cent. at 60 P. P. S.; the percentage rise being practically independent of the voltage applied to the line. The percentage rise in voltage varies, as will be shown, practically as the square of the length of the line and the square

1 See "Alternating Current Phenomena," by C. P. Steinmetz, p. 153.

of the frequency. For the same frequency there will be a rise of about 4% over a line 120 miles long. This means, of course, that the charging current per unit length of line will be 4% greater at the receiver than at the generator. The percentage rise in voltage if this extra current be taken into account will be *less than*

$$\varepsilon < 4\% \, (1 + .04) < 4.16\%$$

That is, the error made is less than .16 of one per cent. of the line pressure. The error will reach one per cent. when the transmission line has a length of about 200 miles.

Aside from the above the regulation of step-up and step-down transformers and generator enter the calculations for the regulation of the system, and since the self-induction of these is usually several times larger than the line of self-induction and is known only approximately—especially the generator self-induction—it is needless to strive for great accuracy in the line calculations.

From the above considerations it will be evident that for an open-circuited line the charging current may be considered the same at all points of the line.

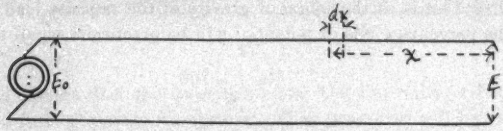

FIG. 6.

In Fig. 6. let

r = resistance per unit length of line.
l = self-induction per unit length of line.
c = capacity " " "
i = charging current " " "
E_0 = E. M. F. at terminals of generator.
E = receiver E. M. F.
ω = frequency.
L = Total length of line.

The charging current crossing the element of line dx at distance x from the receiver is

$$i_x = -Ej \, cx\omega$$

($-j$ is an operator to show that the current is 90° in advance of the pressure.)

The E. M. F. de consumed by the element of line dx is (receiver open-circuited)

$$de = -j\,E\,c\,\omega\,x\,(r - j\,l\,\omega)\,dx \tag{10}$$

Integrating this between the proper limits we get

$$e = -j\,\frac{i\,x^2}{2}\,(r - j\,l\,\omega)$$

$$= -j\,\frac{i\,x}{2}\,(r\,x - j\,l\,x\,\omega)$$

$$= -j\,\frac{I_c}{2}\,(R - j\,L\,\omega) \tag{11}$$

In the last equation, I_c is the charging current, L is the self-induction, and R is the resistance of the total length of line.

From equation (11) we see that if the charging current were the same for each unit length of line it would be mathematically correct to assume the line capacity concentrated at the center of the line, that is, at the center of gravity of the capacity load.

The percentage rise of potential will be practically equal to

$$\varepsilon = \frac{C\,\omega\,L\,\omega\,100}{2},$$

in which C is the total capacity of the line. C and L are proportional to the length of line, and hence, the percentage rise in potential varies practically as the square of the length of line and the square of the frequency.

From equation (11) we get for the generator pressure

$$E_0 = E + e = E - j\,\frac{I_c}{2}\,(R - j\,L\,\omega) \tag{12}$$

As has been shown, I_c may be calculated by the equation

$$I_c = E\,C\,\omega$$

$$I_c = E_0\,C\,\omega$$

without appreciable error in the result of the percentage rise in pressure.

Graphically, equation (12) is as represented in Fig. 7.

$o\,a = E$ receiver.

$$a\,b = -\,j\,\frac{I_c\,R}{2}.$$

$$b\,c = \frac{-\,I_c\,L\,\omega}{2}.$$

$o\,c = E_0$ at terminals of generator.

Suppose, now, we consider the receiver circuit loaded, and calculate the error made by assuming the charging current the same at all points of the line. Let the generator pressure be p per cent. higher than the receiver pressure, that is,

$$E\,o = E\left(1 + \frac{p}{100}\right)$$

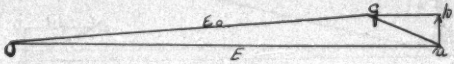

FIG. 7.

and assume that the potential along the line falls on a straight line from generator to receiver. (The true error will be less than that calculated with this assumption, since the pressure falls more rapidly at the generator than at the receiver.)

The charging current per unit length of line at a distance x from the receiver circuit will be

$$i_x = i\left(1 + \frac{p\,x}{L\,100}\right)x.$$

(L is the total length of line; i is the charging current at receiver circuit.)

Suppose the angle of lag of the receiver load to be θ, then, the total load current may be written

$$I = I\cos\theta + j\,I\sin\theta.$$

The current crossing the element of line $d\,x$ is

$$I_t = I\cos\theta + j\,I\sin\theta - j\,i\left(1 + \frac{p\,x}{L\,100}\right)x.$$

The E. M. F. consumed by the element of line dx is

$$de = \left[I\cos\theta + jI\sin\theta - ji\left(1 + \frac{px}{L\,100}\right)x \right](r - jl\omega)\,dx.$$

Integrating, we get for the E. M. F. consumed over the line

$$e = I\cos\theta\,(R - jL\omega) + jI\sin\theta\,(R - jL\omega) -$$
$$j\frac{I_c}{2}\left(1 + \frac{p}{3\times 100}\right)(R - jL\omega) \qquad (13)$$

The percentage rise due to charging current will be *less than*

$$\varepsilon = \frac{C\omega}{2}\left(1 + \frac{p}{3\times 100}\right) L\omega\, 100.$$

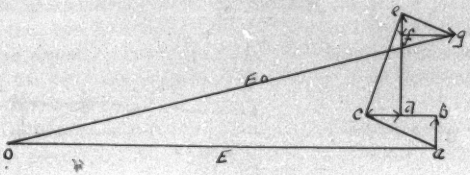

FIG. 8.

If we take $C\omega \times \frac{L\omega}{2} \times 100 = 4$, that is, a line about 120 miles in length, and give to p a value as high as 20—the generator pressure is 20% higher than the receiver pressure—we get

$$\varepsilon = 4\%\left(1 + \frac{20}{300}\right) = 4\%(1 + .06) = 4.24\%.$$

The error made by assuming charging current constant is about one-fourth per cent. of the line pressure.

It is evident, then, that either for a loaded or unloaded line the charging current may be considered constant. Equation (13) may therefore be written

$$e = I\cos\theta\,(R - jL\omega) + jI\sin\theta\,(R - jL\omega) - j\frac{I_c}{2}(R - jL\omega).$$

The pressure at generator terminals is

$$E_0 = E + e$$
$$= E + I\cos\theta\,(R - jL\omega) + jI\sin\theta(R - jL\omega) - j\frac{I_c}{2}(R - jL\omega).$$

This equation is represented graphically in Fig. 8.

$$a\,b = -j\,\frac{I_c\,R}{2}.$$

$$b\,c = -\frac{I_c\,L\,\omega}{2}.$$

$$c\,d = +I\cos\theta\,R.$$

$$d\,e = -j\,I\cos\theta\,L\,\omega.$$

$$e\,f = +j\,I\,R\sin\theta.$$

$$f\,g = +I\,L\,\omega\sin\theta.$$

Instead of combining the currents geometrically as we proceed from receiver to generator we see that we may consider each

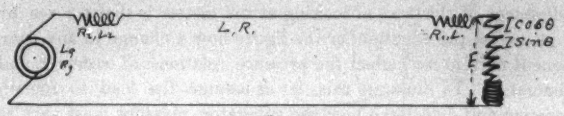

FIG. 9.

component of the receiver current as flowing over the entire line impedance, and the capacity current as flowing over the impedance from the center of the line to the generator. Looking at the matter from this point of view the E. M. F. at the terminals of the generator, or the total E. M. F. generated, may be at once written out for any line.

Let in Fig. 9.

R_1 = equivalent resistance of step-down transformers.[1]
R_2 = " " " step-up transformers.
L_1 = " self-induction of step-down.
L_2 = " " " step-up.
$R\,g$ = " resistance of generator.
$L\,g$ = " self-induction of generator.
R = resistance of line.
L = self-induction of line.

1 It is customary to convert all pressures to equivalent full-line pressure. If r_1 is the resistance of primary transformer and r_2 the resistance of the secondary, the equivalent resistance R_1 is calculated by the formula

$$R_1 = r_1 + r_2\,n^2,$$

n being the ratio of transformation.

The equivalent self-induction of transformers is determined from the ohmic pressure-drop and the short-circuited regulation.

Also let

$$L_t = L_1 + L_2 + L_g + L.$$
$$R_t = R_1 + R_2 + R_g + R.$$

The E. M. F. generated is

$$E_g = E + I\cos\theta\,(R_t - j\,L_t\,\omega) + j\,I\sin\theta\,(R_t - j\,L_t\,\omega) - j\,I_c\left(\frac{R}{2} + R_2 + R_g\right) - j\left(\frac{L}{2} + L_2 + L_g\right) \qquad (14)$$

The figure representing this will be similar to Fig. 8. Each component current is represented by the pressure triangle corresponding to the impedance over which that current flows. That is, each component current may be considered as producing the same effect as though no other current flowed over the line. The advantage of this way of looking at the matter is that we see by a glance at the equation or the figure how a change in any component current will affect the pressure relations of receiver and generator. To illustrate this, let us assume the load to remain constant and determine how the generator pressure must vary to give constant receiver pressure for any change in power factor of the load.

The charging current remains constant; therefore, the triangle A B C, Fig. 8, does not change in magnitude or position. Since the load is assumed constant, the value $I\cos\theta$ is constant and, consequently, the triangle C D E does not change. The only variables are I and $\sin\theta$. We have, however,

$$E\,I\cos\theta = W\,(\text{a constant})$$

$$I = \frac{W}{E\cos\theta}$$

and

$$I\sin\theta = \frac{W\tan\theta}{E}.$$

The triangle E F G always remains similar to triangle C D E. The point g, therefore, moves on the straight line $e\,g$ (if the load current is leading, $e\,g$ must be drawn in the opposite direction) for variable power factor. The length $e\,g$ increases directly as $\tan\theta$ and is drawn at right angles to $c\,e$.

Equation (14) may be solved for E_g algebraically most easily by writing

$$E_g = \left[E + I \cos\theta \; R_t + I \sin\theta \; L_t \, \omega - I_c \left(\frac{L}{2} + L_2 + L_g \right) \omega \right]$$

$$- j \left[I \cos\theta \; L_t \, \omega - I \sin\theta \; R_t + I_c \left(\frac{L}{2} + L_2 + L_g \right) \omega \right]$$

and adding the terms in the square brackets before taking the square root of the sum of the squares. Laid out on paper to a large scale it will be found that results sufficiently accurate for most practical purposes can be obtained with a small amount of labor. Another advantage of the graphical method is that it presents to the eye a picture of the entire circuit.

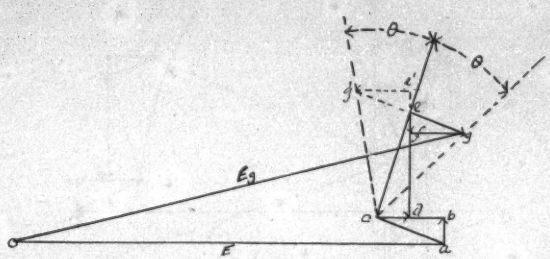

FIG. 10.

The method of finding the regulation for variable load and constant power factor is shown in Fig. 10.

The magnitude of $c\,e$ is proportional to I, that is, proportional to the load for constant power factor, since

$$c\,e = I \cos\theta \, (R_t - j \, L_t \, \omega);$$

the magnitude of $e\,g$ is proportional to the load also, since

$$e\,g = j \, \frac{W}{E} \tan\theta \, (R_t - j \, L_t \, \omega).$$

$e\,g$ is always drawn at right angles to $c\,e$. The triangles $c\,d\,e$ and $e\,f\,g$ are always similar and for constant power factor increase in the same ratio. While the point e moves along $c\,e$, the

point g moves along $c\,g$, the line $c\,g$ making an angle θ with $c\,e$. If the current leads by the angle θ the locus of g will be along the $c\,g'$.

In Fig. 11 the arc of a circle has been drawn with 0 as center and o c as radius. If the receiver pressure is to remain constant with constant generator pressure, the locus of g must be on the arc of this circle.

If there is an inductive receiver load the regulation will be very unsatisfactory unless $f\,g$, Fig. 10, decreases more rapidly than $c\,d$ increases. $c\,d$ increases with the load, $f\,g$ increases or decreases as

$$\frac{W}{E}\tan\theta$$

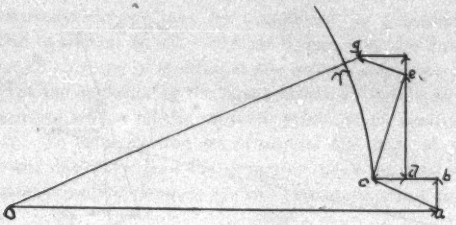

FIG. 11.

increases or decreases. On an induction motor, as the load increases the lag decreases, therefore, a load of this kind after starting does not interfere very much with good regulation. The regulation of the receiver for constant pressure is most difficult when we have a synchronous motor which is carrying a variable load, such as a street railway load.

It is seen from Fig. 11 that in order to keep the receiver pressure constant the leading component of current $I\sin\theta$ must increase as the load increases or θ must change from lag to lead. This can, of course, be done when a synchronous motor is running a street railway generator by putting a shunt and series winding on the field of the motor. For the sake of economy θ is usually changed from lag to lead as the load increases by under-exciting the motor for loads below the average load, and

over-exciting for loads above the average. In Fig. 12 suppose

$$I \cos \theta \, (R_t - j \, L_t \, \omega),$$

which is proportional to the power intake of the motor, is represented by the triangle $c\,e$ at full load, by $c\,e'$ at average load and by $c\,e''$ at no load. With $o\,e'$ as radius draw with 0 as center the arc of a circle through e'. Then at full load the motor must be over-excited so that the length

$$e\,g = I \sin \theta \, (R_t - j \, L_t \, \omega)$$

will reach the circle. Similarly at no load the motor must be under-excited so that $e''\,g''$ will reach the circle.

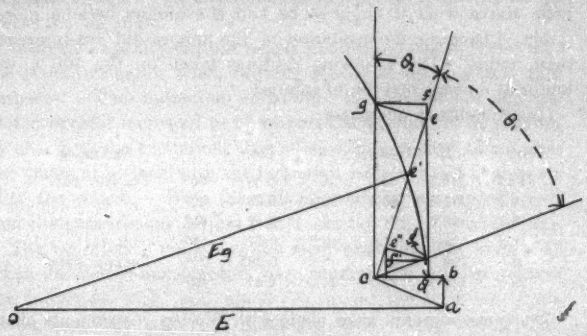

FIG. 12.

By laying off the pressures to a large scale the angles θ_1 and θ_2, Fig. 12, by which the current must lag and lead at no-load and full-load respectively, may be very closely determined. From the constants of the motor it will be possible by the aid of the synchronous motor diagram to determine the excitation for no-load and full-load to give constamt receiver-pressure with constant generator-pressure. The motor may then be run as a generator and the no-load excitation set to the value determined. The current in the series field coil corresponding to full-load on the motor could next be adjusted by the series field shunt until the pressure developed by the motor as a generator corresponded to the full-load excitation as found above. The motor would

then carry its load without causing much variation in the receiver-pressure. It is necessary to know only the no-load power of the motor and the self-induction and resistance of the entire circuit including that of the generator and motor.

Some Transmission Line Troubles.

At the end of the two-phase forty-mile transmission line there were in operation two shunt-wound synchronous motors, 100 K.W. and 50 K.W., running street railway generators. It was found that these motors behaved very badly at no-load and not all satisfactory at all loads.

At no-load the motors would take almost full-load current and were very unstable, falling out of synchronism for a sudden small increase of load. At about full-load the current would be but little above what it ought to be and the motors became more stable. Changing the excitation of the motors did not improve their action. The following readings taken on the 100 K. W. motor at no-load may be of interest.

(Instruments in one-phase.)

I	E	$Wa = IE$	W	Cos θ	θ	Excitation
18.2	111.5	20.2	10	0.49	60°	For min. cur.
18.4	113.5	20.9	10.4	0.49	60°	" "
19.3	110.9	21.4	9	0.42	65°	" "
18.8	115	21.6	10.2	0.47	62°	" "
30	119	35.7	8	0.225	77°	For min. watts.
20.8	116.5	24.2	11.2	0.47	62°	" "

The measurements were made with Weston instruments that had been checked; the readings were taken on one phase and then on the other. The motors operated across a 2200-volt-line; the value of E obtained by use of 20 to 1 multiplier. The full-load current should be about 22 amperes.

The 50-K. W. motor acted in a similar manner; the no-load current was 14 amperes. A water rheostat was connected in each phase of the 50-K. W. motor; with 8 ohms added the no-load current was 12.2 amperes. The motor at this point dropped out of synchronism on adding a small length of shafting.

There was no "hunting" of the motors. Copper bridges were put in between the poles of one motor, but this did not improve its action. Since there was no hunting, the failure of the bridges to improve the action of the motor was predicted. The large no-load current was believed to be due to the difference of wave

shape between generator and motor E. M. F's, the motors acting during part of a cycle as motors, and during the remainder as generators, sending energy back to the system. This explanation seemed to be the only possible one. The difference in wave shape of generator was believed to be due to the magnetizing action of the capacity current distorting the wave shape of the generators. As is well known, the effect of a capacity current is to flatten the E. M. F. wave, and may in an extreme case produce a "jagged" wave.

That the above explanation is the correct one was satisfactorily proved by taking off at the receiver-end of the line a lagging current to neutralize the capacity current. The secondary windings of two transformers were used as induction coils, the magnetic circuit of the transformers having been opened to increase the lag angle.

With the capacity current nearly neutralized it was found that the 100-K. W. motor when running a piece of shafting took 11.5 amperes. The induction coils were then taken out and the motor current increased to 23 amperes, and could not be reduced by changing the excitation. The 50-K. W. motor drew 13 amperes per phase at no-load with the induction coils out and 3 amperes with the coils in. With the coils neutralizing the capacity current the synchronous motors would not fall out of synchronism.

The variation in voltage at the receiver station was about 10% when the synchronous motors were running the railroad without the induction coils, and about 3% under the same conditions as to load but with the induction coils taking enough current to neutralize the capacity current. This 3% variation of receiver voltage was nearly all due to the change of speed of the waterwheels.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, March 28th, 1900.

The 141st meeting of the INSTITUTE was held this date at 12 West 31st street and was called to order at 8:30 P. M. by Manager Charles P. Steinmetz, who gave the floor to the Secretary to make the usual announcements.

THE SECRETARY:—At the meeting of the Council this afternoon, the following associate members were elected.

Name.	Address.	Endorsed by
BABSON, ARTHUR C.	Student, Electrical Engineering, University of California, Mechanics Building, Berkeley, Cala.	Clarence L. Cory. W. A. Lynn. R. S. Masson.
BARON, MAX D.	Outside Superintendent for Harry Alexander; residence, 61 East 75th St., N. Y. City.	A. S. Hubbard. Fred'k Saxelby. Harry Alexander.
BLACKWELL, FRANCIS O.	Engineer, Power and Mining Dept., General Electric Company, Schenectady, N. Y.	Chas. A. Bradley. Ernst Berg. D. R. Lovejoy.
ESTERLINE, J. WALTER	Instructor, Electrical Department, Purdue University, Lafayette, Ind.	Frederick Bedell. C. P. Matthews. W. E. Goldsborough.
FISH, FRED. ALAN	Assistant in Electrical Engineering, Ohio State University, 229 West 11th Avenue, Columbus, Ohio.	B. F. Thomas. Frederick Bedell F. C. Caldwell.
FOG, CARL F.	Electrician, General Electric Co.; residence, 29 Commercial St., Lynn, Mass	W. C. Fish. Elihu Thomson. E. E. Boyer.
MACOMBER, IRWIN JOHN	Professor of Electrical Engineering, Armour Institute of Technology; residence, 422 34th Street, Chicago, Ill.	Edw. L Nichols. H. J. Ryan. Frederick Bedell.
MARSH, HARRY BOWMAN	President, The Advance Electric Co., 8 West Market St., Indianapolis, Ind.	W. E. Goldsborough. Harold B. Smith. Ralph W. Pope.

MOREHEAD, JOHN MOTLEY	Engineer, Union Carbide Co., 157 Michigan Ave., Chicago, Ill.	I. R. Edmands. P. M. Lincoln. W. R. Kenan, Jr.
MORTIMER, JAMES D.	Student, Electrical Engineering, University of California, Mechanics' Building, Berkeley, Cala.	Clarence L. Cory. Wm. A. Lynn. R. S. Masson.
OFFINGER, MARTIN HENRY	Head of Electro-Mechanical Dept., Buffalo Commercial & Electro-Mechanical Institute; residence, 304 Pine St., Buffalo, N. Y.	Edw. L. Nichols. H. J. Ryan. Frederick Bedell.
RUSHMORE, SAMUEL W.	Proprietor, Rushmore Dynamo Works, 24 Morris St., Jersey City, N. J.	M. J. Wightman. J. E. Woodbridge. Joseph Wetzler.
SHAW, AUBREY NORMAN	Draughtsman, A. B. See Mfg. Co.; residence, 298 Carlton Ave., Brooklyn, N. Y.	A. B. See. Samuel Sheldon. A. Treadwell, Jr.
STUTZ, CHAS. C.	Chief Draughtsman, Sprague Electric Co.; residence, 53 West 71st Street, New York City.	George Hill. F. A. Scheffler. Geo. B. Damon.

Total, 14.

And the following associate member was transferred to full membership.

FRANK W. BRADY	Professor of Engineering and Physics. New Mexico College of Agriculture and Mechanic Arts, Mesilla Park, N. M.	

The returns from the nominations were canvassed this afternoon by the Council and the following nominees were selected.

FOR PRESIDENT:—Carl Hering.

FOR VICE-PRESIDENTS:—Gano S. Dunn, Arthur V. Abbott, W. L. R. Emmet.

FOR MANAGERS:—W. S. Barstow, Calvin W. Rice, Cary T. Hutchinson, Ralph D. Mershon.

FOR SECRETARY:—Ralph W. Pope.

FOR TREASURER:—George A. Hamilton.

THE CHAIRMAN:—The next business in order is the reading of a paper by Mr. Joseph Sachs on "The Evolution of Safe and Accurate Fuse Protective Devices." I give the floor to Mr. Sachs.

Mr. Sachs read the paper. (See page 85, February issue.)

Discussion.

Mr. Sachs:—Through the kindness of our fellow-member, Mr. Lieb, of the Edison Illuminating Company of this city, I am permitted this evening to make a very few tests. They will show the action of the fuse under short-circuit conditions at 220 volts. In order to show you any overload tests it would be necessary to arrange resistances and ammeters and take up more time than is possible under the circumstances. The service, as you have noted here, is a 220-volt service. The various experiments will in a measure substantiate the statements in the paper. [Experiments.]

Mr. Gano S. Dunn:—To start the discussion, I will ask a very simple question. I would like to inquire of Mr. Sachs the relative cost of these fuses and the other ones. They burn up so quickly and so easily that, of course, we would like to have them; but can we afford to?

Mr. Sachs:—That is certainly a very important consideration. This superior operation is all very nice—we hear from all sides—but what is it going to cost? The only answer is that superior operation has undoubtedly superior value. The enclosed fuse is more expensive than the type of open fuse heretofore used, but its advantages are so strikingly superior that the additional cost is, to a very great extent, offset. When you consider that you are gaining features unattainable in prior similar devices, accuracy and absolute safety, it certainly seems that you can afford to pay a little more for such protection. Insurance of the nature provided in an enclosed fuse certainly possesses a value.

Mr. Louis W. Downes:—I have been very much interested in Mr. Sachs' paper, for the reason that in the past six years I have been investigating in identically the same line; in other words, studying and developing the enclosed type of fuse; and I will state frankly that I am a believer in the air-drum type of fuse as against Mr. Sachs' principle of a solid-packed fuse, and I have had the opportunity of having many very pleasant discussions with Mr. Sachs on that subject.

There are certain points in his paper that I should like to bring forward for discussion, and certain explanations in regard to the air-drum fuse, which I believe will be of interest. There is one point on page 95 that I would like to call attention to, where he speaks of the enclosed fuse with the air-drum being subject to the same disadvantages of slow oxidation that an open fuse would be. As far as my personal observations have gone, this effect of slow oxidation is negligible in every practical sense. We have had fuses in practical operation, what I might say commercial operation, now for the past four years, and I have tested from time to time fuses that were made four or five years ago and which have been subjected at intervals to current, or to load I might put it, and have found no variation in their carrying capacity whatsoever. Examination of these fuses shows

the same results. In other words, the amount of air contained in the air space is so extremely small that the oxygen present is not sufficient to cause any appreciable oxidation of the metal, and I think Mr. Sachs has rather exaggerated that danger. That is, I am simply quoting my own observations in that line.

He also speaks of the variation in the carrying capacity and the time element which can be produced by varying the air space, and I would like to add somewhat to that and state that the material used for filling also has a very pronounced effect on the time element for any given overload. It has come recently within my observation, in fact, only last week I was making some calibrations on fuses and I found that the variation in the material with which the fuse tube was filled affected the blowing time, at 50% overload, about 125%; and also found with what we call the multiple link fuse, which is shown in Fig. 10, on page 96, that the position of the individual links or strips of fusible metal also affects the blowing time on any given overload, that is, if they are spread out near the surface, with the air space of precisely the same length, you could get a much more sluggish fuse; (or, in other words, the time element is increased) than you do where they are drawn closer together near the center. This is obviously due to the fact that there was less material through which the heat passes to the surrounding surface in order to be thrown off, and in that way we possess possibilities of producing a fuse, within certain limits, of almost any desired time element.

Another point that Mr. Sachs speaks of, in mentioning the metal used, is of interest and importance. In my experience there are very peculiar properties in different metals when subjected to extremely heavy overloads, or those conditions approximating short-circuits where the metal is volatilized practically instantaneously. Some metals apparently can pass from the metallic state to a vapor with very little disturbance, very little of the explosive action that is present with others. I think copper, as Mr. Sachs states, passes with greater difficulty from the metallic to the vapor condition than any other metal that I have come in contact with. I have tried all the common metals. There seems to be explosive force or action there that it is almost impossible to confine. Pure lead, that is, commercially pure lead, passes with great ease, and zinc possesses very pronounced qualities in that direction. Even an exposed zinc fuse can be short-circuited with moderate capacities very successfully, without any great disruptive effects or burning of terminals.

On page 99, Mr. Sachs speaks of the extremely rapid oxidation. I think that it is not wholly a matter of oxidation in this case, because it appears to me that when the metal is converted into a vapor, that can hardly be termed an oxidation, in the strict sense. It is a metallic vapor, certainly, but it does not possess any of the appearance or nature of the oxides. It is that

vapor which being condensed by the surrounding mass and being disintegrated by the surrounding mass passes off and prevents the establishment of an arc.

He speaks of short-circuit tests on 2500-volt alternating and 500-volt direct. I had some peculiar experience in that same direction myself, and I am inclined to think that the effect Mr. Sachs noted, that is, the burning of only a small portion of the strip in the alternating current short-circuit, was due more to an effect on the generator than anything peculiar about the current itself. One night in my laboratory we were going to try a short-circuit test. It happened to be in the winter-time, about five o'clock, and it was rather dark. We tried it and all the lights went out all over the city, and there was naturally a good deal of disturbance. They died down for a short period when the fuse blew, and immediately came up. Apparently the fields of the alternator had been killed momentarily, and I think that is where the result that Mr. Sachs noted came about, although the generator that I speak of was 500 K.W., and the fuse I blew was only 20 amperes nominal capacity, so that the generator was amply big enough to put out the energy, if it had not been that the sudden rush of current reacted on the fields and killed the voltage, so that the voltage across the fuse was extremely small.

MR. SACHS:—That would be a lagging of the current. You note I state here: "It may be due to the inability of the 2500-volt A.C. arc to maintain itself over a greater distance and also to the lagging of the current rush." It doesn't matter if the fields were killed, or whatever caused that lagging.

MR. DOWNES:—I suppose you used the word "lagging" of current in its general, technical sense, that is, lagging of the current behind the E. M. F., under which conditions the current might maintain its full value but come after a sufficient time element.

MR. SACHS:—I should better have said a lagging of the energy rush impressed on the fuse. When I used the word "lag" I meant choking off. Pardon me for interrupting, however.

MR. DOWNES:—I also found that it was possible with those generators, which, I will state, are separately excited, single-phase alternators; we actually found that it was possible to short-circuit or place a 30-ampere fuse directly across the mains and close the circuit without instantly blowing the fuse. That was at 2200 volts. It was possible to close that switch by the hand and open it again before the fuse had blown, so instantaneous was that killing effect on the fields. I would not advise any one to try that experiment with a compound-wound alternator, however.

Another very curious effect Mr. Sachs speaks of, where he mentioned that a portion of the fuse metal was surrounded, part with this active material and part with inert material,

showing that the fuse blew where the active material was, and not at a point where it was surrounded by the inert material. I am inclined to differ with Mr. Sachs somewhat in this matter and to attribute the blowing of the fuse at the point where it was surrounded by the so-called active material to the fact that this possessed less heat conductivity than the other. In other words, the heat at that point was conveyed away less rapidly, and consequently there was what might be called an accumulation of the heat with rising temperature which brought about the results, namely, the melting of the fuse at that point, because that became the point of maximum resistance and temperature.

There is one point that I should like to second Mr. Sachs in most heartily, and that is in respect to the present method of rating that is advocated by the underwriters. It does not meet with my approval at all. I believe that there should be action taken on this in order to put out fuses marked at what they are, and not at some other value. In other words, let us call a one-inch pipe a one-inch pipe, and not mark a one-inch pipe three-quarters of an inch. Mark a fuse for the maximum current that it will carry continuously with a standard temperature, say, 75° Fahr., surrounding air, and you know definitely what you have got. The blowing point can be made for any given overload suitable to meet the conditions of the service, a matter which should be left to the manufacturer.

MR. H. C. WIRT:—I am sorry to have to differ with both Mr. Sachs and Mr. Downes in regard to the rating of fuses. I think we should rate fuses in a commercial way, so that the public using those fuses can be assured that a circuit will always carry what the fuses are marked. I think if you rate a fuse to different time elements that the people who have to use these fuses will not understand them. I have had considerable correspondence with the underwriters regarding the 25% overload, and thoroughly endorse their decision. In fact, I advocated it. I think the fuses should be marked so that they can be used in the ordinary commercial cut-outs and to be certain that they will carry the rated current. I think as soon as you begin to mark fuses 5% overload and have them melt at that point you will get fuses that will melt when they should not melt. You have to make allowance for temperature. Some have to run in boiler rooms, others in cool places. The question is whether a fuse with 25% rating will cause any trouble to any wiring or impair the devices that they are to protect.

I have made investigations and found that under those conditions the wires are not overheated. I think that much of the discussion regarding the open fuse has been conducted with only an imperfect idea of the conditions. For instance, the open fuse has been blamed, because it will allow 100 amperes to pass through for a short time if it is rated for 50 amperes. I think that is no objection to the open fuse. I think enclosed fuses

would do the same thing. The question is if under instantaneous load of 100 amperes the wires which are protected by the fuse will be overheated. My investigations show that under those conditions the wires are not heated as much as under the condition of a slight overload of 10%, or 15%, or something like that. I think there are two objections to the enclosed fuse. One is the cost; I think that is a very great objection. The other is the destruction of the fuse on short-circuit conditions. Mr. Sachs will probably say that that will not occur to his fuse. I know Mr. Downes will say so; but I have tested fuses made by both of them (and I anticipate what the gentleman will say) and I know that a 100-ampere fuse of either type will be destroyed under short-circuit conditions. I acknowledge that short-circuit conditions on many of the open fuses will be much worse, but I think we should all realize the limitations of the enclosed fuse; what kind of an enclosed fuse can be supplied to carry 1000 amperes, 500 volts. I don't know of any enclosed fuse that will do that work.

MR. SACHS:—What was that capacity?

MR. WIRT:—1000 amperes.

MR. SACHS:—At 500 volts.

MR. WIRT:—500 volts under short-circuit conditions.

MR. SACHS:—Do you limit the capacity back of it?

MR. WIRT:—No.

MR. SACHS:—Do you place any limit on the capacity back of it?

MR. WIRT:—No; if you are going to have short-circuit conditions, you must have big capacity back of it. I will give figures on a 100-ampere fuse. I do not know the current, but it is a very large current, of course, and those are conditions that will have to be met. I have tested fuses on a 400 K.W. generator, short-circuited, an enclosed fuse near the machine, and the cut-out was destroyed and if any one had been near the cut-out there would have been danger of serious injury.

MR. SACHS:—If you will pardon me for interrupting you again—was that an over-compounded alternating machine?

MR. WIRT:—No; a direct current 500-volt machine.

MR. SACHS:—Over-compounded—street railway service.

MR. WIRT:—No; it was a rotary converter. Now as regards the objection to the fuse on account of the cost, I would say that if you stop to consider the cost of the enclosed fuse, for a railway car, which must be about 20 cents, and the number that are blown out annually in the United States, and then consider the cost of the simple lead fuses (which are used in a magnetic fuse box, causing them to operate properly) you see that the enclosed fuse is much more expensive, and as the lead fuse is enclosed within a box, it seems to me in the strict sense of the word that it is as much of an enclosed fuse as the strictly cartridge type; that is, there is no fire given out and no trouble owing to the construction of the fuse box.

It would seem to me that Mr. Sachs' test of the two fuses here, showing that the enclosed fuse operated quicker than the open fuse, was not just right, because we do not know for what overload capacities the two fuses were designed for. If the enclosed fuse was designed for smaller overload capacity, of course, it would melt quicker. I am an advocate of enclosed fuses where they can be used, and where they are of an advantage; that is, I advocate them generally for 220-volt work and where the fuses have to go in buildings, where the trouble from leaking is great. I think in a case of that kind we should not mind the increased cost. But I do not believe that the enclosed fuse can be used in every position.

Mr. William J. Hammer:—I think Mr. Sachs' paper is a valuable addition to the literature on this subject, and if I may be permitted I would like to call attention to a contribution to the enclosed fuse development, which I do not think very many

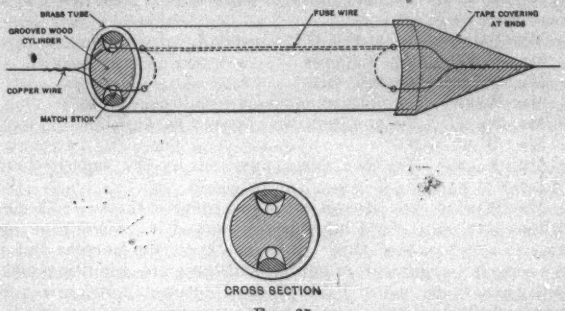

Fig. 25.

of the members here are familiar with, and which came up in connection with the very early days of electric lighting abroad, many of these fuses having been used in both England and Germany. I would like to make a little sketch on the board. As some of the members perhaps are aware, "The First Central Station for Incandescent Electric Lighting in the World" was the Holborn Viaduct Station in London, England, which was started nearly a year before the Edison Pearl Street Station in New York City (*i. e.* Jan. 12th, 1882), and was a complete central station, employing four Edison "Jumbo" steam dynamos, Edison underground tubing, electric meters, indicating and regulating devices, and both incandescent and arc lamps, the latter, together with storage batteries and motors, being used experimentally. At the time when the Holborn Viaduct Station was inaugurated it was customary, both in isolated lighting and upon that central station plant at the time, to always put the switch on

the one pole and the cut-out on the other, because there existed no double-pole cut-outs or double-pole switches at that time. It was customary for the man in putting in an installation to stand (metaphorically speaking) with his back to the dynamo, and take one wire in his left hand and the other in his right, and put his switch always on the right-hand wire and its branches, and put his cut-out on the left-hand wire and its branches or taps. In the Holborn Viaduct Station we found that it was advisable to put a fuse on the other wire as well. They were of the type shown in Fig. 25, and it is interesting to note that the Holborn Viaduct itself was the first street in the world lighted by incandescent electric lighting and Dr. Parker's "City Temple" church on that street was the first church illuminated by the incandescent lamp, and these were fitted with this type of fuse. It is a very simple form of an enclosed fuse, consisting of a piece of brass tubing,

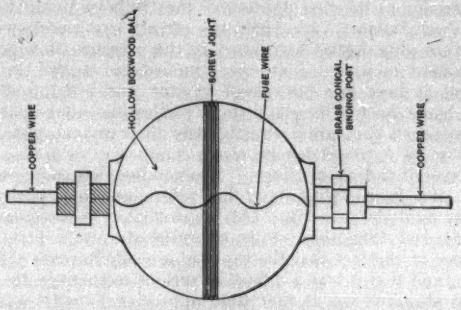

FIG. 26.

inside of which is a cylinder of wood. The fuse wire lies in the groove as shown. Sometimes it laid on both sides. There were a good many of them made with multiple fuses. Laid in the groove on top of the fuse wire was a little piece of wood, like a match, which very nearly filled the space. The copper wire at each end of the wooden cylinder was passed through a small hole near the end and was fastened back on itself forming a loop, with the fuse wire running from one wire to the other, and if multiple fuses were employed, fuse wires were put in grooves on both sides. (Another form used considerably, and which was the first form of "bug cut-out" ever used in inside electric fixtures, is shown in Fig. 26.) Much important pioneer work was done at the Holborn Viaduct Station. Some of the first insulating joints on gas and electric fixtures were made and used over there. Some of the first switches and circuit-breakers for use with heavy currents and a good many other things that have come into com-

mon practice were tried there on a more or less extensive scale. This fuse had many advantages in addition to its being a very simple and inexpensive thing. The ends were usually wrapped around with tape. All that was necessary, if that fuse blew without destroying the whole fuse or making it necessary to put another one in, was that this brass tube be slid along the wire, the match lifted up, the new fuse wire put in and the sleeve slipped on again. Barrels of these fuses were used in both England and Germany in the early days of electric lighting, the fuse wire being 60% lead and 40% tin.

I note that there is a picture in Mr. Sachs' paper of one of Mr. Edison's early fuses or lead plugs. I hold in my hand one of the very first ones of this type, which is most interesting historically. The first incandescent electric lamp which was ever lit from an incandescent electric lighting station was connected with this identical fuse plug. In that case it was used as a switch. On the occasion of the first lighting of the Holborn Viaduct Station, which was January 12th, 1882, the circuit was closed with that little fuse plug, by my own hand, in the presence of a gathering of eminent men, and I at once removed and tagged the plug as you see it here and have kept it ever since; the first capped plugs came over to England shortly after the above date. Mr. Edison sent a cablegram shortly after their arrival, which read: "Vapors of a conductor are also a conductor. Punch a hole in every one of the safety plugs." I remember that cablegram very well. Mr. Sachs' paper and his references to vaporized conductors reminds me of it. This showed that in those early days of 1881 and 1882 they really appreciated quite a little the importance of the fact that the vapor of a conductor was also a conductor, and that it was a matter of serious moment in the Edison fusible plug, and we at that time appreciated that it was of importance to fuse all circuits, and especially to fuse both poles of each circuit, the desirability of which had not been realized up to that time.

MR. F. V. HENSHAW:—We have always thought the subject of fuses rather a simple one, I think, in the past, but it certainly is quite otherwise, and among the many interesting features of these enclosed fuses, I think about as interesting as any is the matter of the filling of these tubes. I have seen a great many experiments in enclosed fuses, and the results sometimes were rather terrific. I was very much interested in Mr. Sachs' description of his active material which combines with the oxide of the metal. Now, in the experiments which I saw, it struck me that that is precisely what you did not want. Some of these tests were made on tubes filled with various silicates and a condition which gave a most violent arc resulted, and after the thing had cooled down a beautiful little tube was found, vitrified on the inside and rough on the outside, and as long as that tube was there the arc would simply roar away inside. Further experi-

ments show that substances that were incapable of melting or of forming any slag acted in quite the opposite way and the arc was choked out completely. So I was surprised at the fact that this substance which combines with the fuse metal has been found to be an advantage.

Mr. Downes:—Speaking of the results Mr. Wirt got from this 100-ampere fuse, I would like to say that a good many of the difficulties Mr. Wirt experienced have been overcome, and we are making fuses now which I will not hesitate to subject to a short-circuit at any time. A few weeks ago I had occasion to make some short-circuit tests and they all happened to be on 100-ampere fuses. I spent several days in the laboratory working on that, and short-circuited, repeatedly, 100-ampere fuses without any difficulty whatsoever. There was no arcing, no disruption of the fuse or parts of the fuse, or the fuse connections in any shape or fashion, and there was no lack of energy back of the fuse, because I had two 500-k.w., 500-volt generators running in multiple, and also in multiple with this was a very large storage battery; so that the instantaneous current was something enormous. These effects are accomplished by providing the fuse with suitable vents to take care of the vaporized metal. If you try to enclose a fuse, no matter what filling you put into it, whether it combines with the metal or whether it does not, and totally enclose it and don't allow escape for the gases under short-circuit conditions, it will invariably explode; that is, I mean, in the larger capacity; and explode with terrific violence. If, however, you provide that fuse tube with vents at suitable portions,—do not put it at the immediate center.—you can short-circuit the fuses of large capacity with perfect safety.

In speaking of the effect of material combining with the fuse metal that Mr. Henshaw has just mentioned, I would like to state that I observed very curious properties in certain materials that tend to suppress arcing. I have made tests in that direction, trying almost every material that I could find mentioned in text-books; that is, material that was sufficiently cheap to be utilized for the purpose, and find that some possess very pronounced and remarkable properties towards suppressing an arc. The tests were made in this way: A small glass tube was provided with a metallic bottom and a plunger, a small copper wire was run down through the top, and the material that the test was made on was put into this tube, and contact was made by pressing the plunger down until it struck the bottom. The current used being on a 500-volt circuit with lamp-bank as load. To establish the arc the plunger was drawn slightly away from the bottom. With certain materials there was a tendency to aid the arc, largely due to the reduction of the surrounding materials and the presence of the water of crystallization, which tended to carry over the current and maintain an arc. With other material as soon as the point was drawn back the arc would be almost

immediately extinguished. I have not been able to determine just what that effect is due to. But I attribute it to the presence of certain gases that are formed in the first flash on the circuit as the plunger is drawn away.

MR. C. O. MAILLOUX:—The troubles which we find with fuses in isolated plants are largely increased with the voltage. The introduction of the 220-volt two-wire system, that is to say, the use of 220 or 230-volt lamps has necessitated the making of cut-outs which are suitable for that voltage, and the difficulties due to arcs at the cut-out panel have greatly increased; one might be tempted to say that they increase in a higher power than the square of the voltage. It is in such cases that a fuse can be depended upon to go off at a certain fixed excess of normal rate is valuable, especially if it can be depended on to go off without setting off the rest of the cut-out fuses. It has often come to my knowledge within the last two years that an ordinary cut-out of the "panel" type, in which the fuses are connected between bus-bars, has had all the circuits on one side blown out by the operation of one single, innocent 10-ampere fuse. The disruptive effect is very great, and then the arc is necessarily longer, owing to the higher voltage, and that arc is apt to rise until it starts a short circuit, which produces the same result across the next pair of bars above, and we have a "blow-up" process which starts at the bottom of the panel and ends at the top. In some cases the amount of vapor produced might be sufficient to force open the cabinet door. We may find in an establishment, for instance, where motors are run, a fuse that is rated for 25 or 30 amperes. Suddenly the motor is overloaded or stalled and the fuse blows. The current at which the fuse blows may not exceed 75 amperes, yet it has happened that in consequence of that 75 amperes the whole establishment has been shut down and had its current supply cut off, because that 75 amperes would cause a larger fuse to blow perhaps on the main or on the feeder, or even go as far as the switchboard. and if we are unfortunate enough to be operating with a closely loaded plant and have electro-magnetic cut-outs which have not much margin in their adjustment, the result will be that one of the machines will be cut out by the action of the circuit-breaker. Instantly the others are all overloaded beyond their capacity and they will also become cut out. I have heard of similar instances which have occurred, and in one case it was found necessary to screw the weights or springs of the electro-magnetic cut-outs until they became practically inoperative; that is, until their capacity was at least 100 or 150% above normal load. It seems to me that the enclosed fuse will have a great sphere of usefulness in cases of this kind where safety and especially where reliability of service are conditions which dominate all considerations of price and of cost. There are difficulties, however, which still remain to be met, and these are the methods of connecting the fuses. It does

not seem to me that the mechanical conditions are properly met or provided for. The terminals do not get as good contact as they might. I have seen cases where the contact of the terminals to these protective fuses was such as to become warm. It would produce heat perhaps enough in some cases to operate the fuse. There does not seem to be that interchangeability between the various fuses which is the desirable feature in all American work where all like parts are made interchangeable. I have found these arcless fuses very useful and in fact have found them indispensable in many cases even as they are. I have had to use them where all other methods have failed. But I think they are still far short of the sphere of usefulness to which they will attain, when the mechanical details, especially the methods of making terminal contacts, have been worked out a little more perfectly and satisfactorily.

MR. FREMONT WILSON:—There is not much I can say that has not been covered by my old associate, Mr. Mailloux, except that I might refer to Mr. Dunn's question as to first cost. It is a very pertinent question. I sent for Mr. Sachs some time ago and asked him to go to one of the large hotels in this city and see if he could not induce the proprietor to put in his fuses. I had been about driven distracted with arcing of 230-volt fuses, and the question of cost came up, and as is known all hotel men are fiends on cost. They never look at the cost in the proper light as we consider it. Mr. Sachs was very neatly turned down. The fuses have not been introduced, but they will have to go there, because the panel-boards are being disrupted very rapidly. The proprietor uses a cheap make of lamp. He won't buy what may be considered the only lamp there is that will work on the 230 volts; it is unnecessary to mention the name of it. The lamp he uses, short-circuits across the base with the result Mr. Mailloux has just stated, and although the circuits are protected by so-called 10-ampere fuses, time and time again a feeder circuit breaker of 100-ampere capacity has opened, and in one case a main circuit breaker opened and threw a 150-K.W. machine out, and one-half the hotel was in total darkness, owing to a lamp short-circuiting across the base. With Mr. Sachs' fuse such a thing is absolutely impossible, as I see it. I have tried to get people to use it, but they come back to the cost. But they have got to come to it, and Mr. Sachs has simply got to be patient, as lots of us have had to be. They are bound to win out on isolated plants. The circuit-breakers we have now are so delicate, operate so quickly, and the short-circuit develops such an enormous rush of current momentarily either in the lamp-base or in the socket that you must have something of this sort. I have to deal with the question now as engineer for several insurance people, and the question of to-day is, what are we to do with panel-boards where they have the ordinary fuses on 230 volts? and I have had to make a recommendation and do not know where I am coming out on it, to take

out the panel-boards and put in ones with the enclosed fuse, such as we have here to-night.

Mr. Mailloux:—I wish to add a few words on a point which was the principal point I previously intended to discuss and which I forgot. I am in doubt as to the expediency of providing cut-out devices for the generators when they exceed a certain size. As you know, in central stations no one thinks of putting in fuses unless they are so set or so designed that they will only give way at the actual burning or destruction point of the machine. In very large installations I think that more harm may occur from having a large unit cut out as the result of overload than would result if it were allowed to run overloaded. This matter was of very great importance, especially in a case like the Astoria Hotel, where an occurrence such as I described a little while ago wherein the operation of one fuse led to the successive cutting out of all the dynamos and threw the whole establishment in darkness, would be simply inadmissible—it would cause a panic and might result in the loss of many lives, to say nothing of the discomfort, inconvenience and annoyance it would cause. At the time that the Astoria Hotel plant was designed, the matter was very seriously considered and discussed, not only with the owners but with all parties interested, even with the insurance authorities, and it was deemed, on the whole, best to make the arrangements such that the machines would operate substantially the same as under central station conditions. The fuses were placed at the rear of the board, where, if they did go off, they would not hurt or blind anybody that happened to be in front (for no one contemplates with very much pleasure the going off of a 300-kilowatt fuse), and they were so proportioned that they would take about twice the normal capacity of the machine to fuse them. But as it would not be pleasant to operate with 100 or 150 overload, a relay device was introduced in one of the dynamo leads and so arranged that it would operate and close a local circuit and ring an alarm-bell and show a red light. It seems to me that this method of giving the attendant a hint that it is time to reduce the power or to do something is much better than to shoot off a cannon, and it is probably not more dangerous. I believe for myself that when we reach a unit as large as 100 kilowatts it is time to trust more to the care of the attendant and his ability to act in an emergency than to trust to automatic cut-outs or fuses, because I think that their unexpected action, their going off at the wrong time or at a critical moment, is likely to produce far more mischief than even the burning out of an armature or the destruction of the machine itself. It is certain that in a case like the Astoria Hotel the owners would far rather pay for a new armature or a whole new generator than have to pay the damages that might result in consequence of a panic due to the sudden failure of the current supply. There are numerous other similar cases. The Astoria Hotel illustrates the point, because it is the largest

isolated plant in this section. But the same troubles occur to a greater or less extent in numbers of installations where the plant is much smaller. I think it might be well for the INSTITUTE to consider this matter, since the insurance authorities are likely to be influenced by our views in the prescribing of rules on the subject.

MR. W. C. WOODWARD:—The plant with which I am connected as engineer is to-day the largest plant in this country, operating a 470-volt 3-wire system, using 235-volt incandescent lamps. The plant consists of direct-connected generators in units of 500 kilowatts, operating in multiple with a storage battery system of a capacity of 760 amperes on each side, discharging into the 3-wire lighting system, the network of main conductors in this system being underground in all cases; the feeders the same. Of course in designing this system it became necessary to provide for the difficulties that had been encountered in the 3-wire system of 220 volts on the outside, recognizing, of course, the fact that the troubles would be magnified very largely in the case of the higher voltage. New devices had to be designed, and they were designed theoretically entirely, as there was no practical commercial data on which to base calculations. It became necessary to introduce currents of large capacity and high voltage, protected by fuses, and the enclosed fuse was used in every instance through the entire installation, both underground and in the consumers' premises. I will state that the fuses have operated on several occasions and operated as it was intended they should. I will substantiate Mr. Sachs' statement that copper gives a much more destructive result at the terminal than aluminium. We have short-circuited bus-bars and mains with copper, producing dead short-circuits, and the protecting fuses in every case have blown. Where the bus-bars have been actually short-circuited by copper strips, of course there has been considerable destructive arcing. Where it has been aluminium the arcing has been less destructive. We find no trouble in the 235-volt enclosed fuse, and I think that Mr. Sachs can be substantiated at every point, as far as the enclosed fuse is concerned, that it is the only device that should be used in breaking circuits of high voltage, or, in fact, of any voltage.

MR. STEINMETZ. [Secretary Pope in the chair.] I shall confine myself strictly to the topic of the paper. The paper and the discussion following it have been very interesting in dealing with fuses suitable for circuits of moderate capacity and relatively low voltage. For such circuits fuses are generally and successfully used, but I must caution you not to generalize too much, as has been done by the author and by many of the speakers, regarding the use of fuses, especially in circuits of large capacity and high voltage. Fuses, circuit-breakers, switches and other protective devices have the common feature that judgment on their value can be derived only by experiment, or tests, and that such tests

are rather difficult to make, and the facilities for reliable tests are not always, or even rarely, available where large powers and high voltage circuits are considered, and furthermore that the liability to be misled by inconclusive experiments and thereby to arrive at erroneous conclusions is extremely great, as great almost as it is with the primary battery.

For instance, in the paper as read, and by many speakers, reference has been made to the short-circuit tests of fuses. Now the mere short-circuit test of a fuse is entirely valueless regarding the action of the fuse. I refer here to fuses intended to control large power; short-circuit tests frequently are more than valueless, they are misleading in so far as they are liable to make the fuse appear to be able to do a thing which it is not able to do. Take for instance, the tests given here in the paper as referring to a fuse on a 2500-volt alternating circuit and a 500-volt direct current circuit. Now this should read, "the tests of a fuse on a circuit on which, before the fuse was connected, 2500-volts alternating existed, and after the fuse was connected a very small voltage, very few volts existed and a current limited by the armature reaction, or the short-circuit current of the alternator, that is a current of unknown value, but probably quite moderate, was flowing until the fuse ruptured, and after the fuse had broken, the circuit the voltage gradually, with an unknown velocity, rose again to the initial value."

You see, instead of taking the trouble of short-circuiting a 2500-volt alternator, you might short-circuit a few storage batteries with the same result. The result depends entirely upon the short-circuit capacity of the alternator and upon the speed with which the alternator, after opening the circuit, recovers its voltage. That is, the test gives nothing regarding the current and the voltage ruptured by the fuse. This is the reason why in the test referred to the action of the fuse was much more violent on a 500-volt continuous current circuit, merely because in the 500-volt continuous current circuit, with the large magnetic field of its generator, the magnetic field held on after the fuse blew, and the voltage recovered rather rapidly after the blowing of the fuse, while the alternator with its high armature reaction and relatively weak field entirely lost its voltage and only later recovered after the fuse had already opened the circuit. This explains the discrepancy of opinion on the action of the 100-ampere enclosed fuse which, according to Mr. Sachs, should rupture a 500-volt circuit, and according to Mr. Wirt merely blow to pieces. Mr. Wirt put the fuse on a rotary converter which transforms from an alternating system of unknown but probably very large capacity, while Mr. Sachs had only small power behind the fuse.

So you see short-circuit tests are misleading and rather meaningless, and the conclusions derived therefrom regarding fuse protected circuits are not safe.

Let us then see how we should test a fuse to see whether it is reliable. One way would be if you want to make short-circuit tests to short-circuit a long line, or better a cable, at the receiving end by the fuse, with such generator capacity at the other end of the cable that with the short-circuit on one side the voltage is maintained at the other end. Then, while the voltage drops down to zero by the short-circuiting of the fuse, in the moment when the fuse ruptures, the voltage instantly recovers because it is constant at the other end. You see here you get the maximum velocity of voltage recovery. If you can rupture such a 2500-volt circuit with a half-inch fuse it is more conclusive than to short-circuit a Niagara generator for instance, by it, since the generator drops down in voltage. A still more severe test, a test however which represents conditions very frequently met, is not to short-circuit the system but to insert the fuse between a generator and a synchronous motor or converter, and then gradually load the converter or synchronous motor until the fuse blows. That is, see whether the fuse ruptures the circuit between a generating system and a receiving system, which latter contains a live counter E. M. F. What you get in the moment of rupture is this: While the fuse is still there, the generator of say 2200 volts sends current through the circuit against the counter E. M. F. of the synchronous motor of say 2000 volts. When the fuse melts and the circuit begins to open, the generator and the motor maintain their E. M. F's, but rapidly, due to the opening of the circuit, the current decreases and the synchronous motor begins to slow down. It drops one-half wave behind, but then the 2000 volts of the synchronous motor are not in opposition to the 2200-volt generator, but are in phase and you have 4200 volts across the fuse. That is, the voltage is practically doubled, and if you can break away then with the fuse you can rely upon it, but not if it opens a circuit after the circuit has lost its voltage.

But there is one feature to be considered, which was not brought out by the paper, because the paper really is based on experience with relatively small capacities and small powers, while this feature is the dominating feature in circuits of large capacity and high power. That is, the fuse or other protective device must open the circuit so as not to endanger the circuit. Where you have a circuit containing cables or long distance transmission lines of very high voltage, you can not safely rupture the circuit instantly. The first condition of any circuit-breaking device is that you open the circuit so as not to cause any excessive rise of voltage by resonance between capacity and self-inductance. This greatly limits the action of the circuit-breaking device, and it is a condition which practically excludes fuses from all such circuits, or at least makes them rather undesirable. The action of a fuse is not a gradual opening of the circuit in a high potential circuit, but in the moment when the fuse blows, an arc starts and holds on, with increasing length flaring up until it suddenly

breaks. The decrease of current is first quite moderate until the moment when the arc ruptures, and then you get a sudden break of current which causes an oscillating discharge and destroys your cable, or at least makes a pin hole, and the next day another one, and after half a year or a year, the cable begins to break down, and these break-downs occur with increasing frequency, until the cable has to be replaced. The result is that as far as possible in high voltage circuits, fuses and other overload protecting devices are not used, but a rigid connection between generating system and receiving system, and special care taken to make it impossible to open the circuit while alive. Obviously where the central station feeds a number of cables or distribution lines and the liability exists of troubles in one circuit or the other, you must be able to break away from the system, and there you have to design a circuit-opening device which opens gradually and slowly enough not to cause a dangerous rise of voltage. Attention has been drawn to the explosive effect of fuses and how to guard against it. A certain violence, however, is inherent to and unavoidable in opening circuits conveying large powers; if we control a high-voltage large power alternating system, we have seen that we must not open circuit instantly, because instantaneous break of the circuit causes liability to destruction of cable, transformers, etc. The circuit-breaking device must open the circuit gradually, during a time in magnitude comparable with the time of one-half wave. That means in a 25-cycle circuit comparable with one-fiftieth of a second. Consider what power you develop at the point of break if you open a short-circuit gradually, that is, during one-hundredth of a second, on a large power distribution system as that for instance of the Metropolitan Railway here in New York City. At the point of break, power is developed about equal to the explosion of some ounces of gunpowder. Then it is not possible to open the circuit entirely without explosive effect.

You see then that the conditions as soon as you come to a circuit of very large capacity and high voltage, are entirely different from those experimented with by the reader of the paper, and all other considerations are entirely overpowered by the condition that you must open the circuit under any condition, and that by a device which will open without resonance rise, and by expending during the opening as much power as is developed during the time of opening; that is, during a time comparable in magnitude with the time of one-half wave or one-half period. I do not know whether fuses can be made to do that, but I very much doubt that they can, due to their inherent feature of opening the circuit suddenly.

MR. SACHS:—Mr. Steinmetz's remarks are certainly pertinent to the paper. They speak of things that I have not done yet, but I am perfectly willing to do. I have not been afforded the facilities to short-circuit at the end of a mile or two of underground cable, for the simple reason that nobody would furnish

the cable. I feel sure, however, that I can open a circuit under such conditions with less injury to the cable than, perhaps, Mr. Steinmetz considers fuses capable of doing.

I have not been able to short-circuit a system of the size of the Metropolitan Company's system, for the reason that neither the Metropolitan Company nor anybody else wanted to deliver over their system for this purpose—at least not in its entirety. You appreciate thoroughly that the first experimental device may miss fire. It is then simply a case of blowing up the system or blowing up the fuse.

In regard to gunpowder and gunpowder fuses, Mr. Steinmetz, when he made that remark, had, as we perhaps would say, quite a good deal more than that remark up his sleeve. Mr. Steinmetz has recently invented a veritable gunpowder fuse. He has placed a fuse wire surrounded by some explosive compounds in a tube, and then blown the fuse wire inside of the surrounding environment, veritably getting the explosion that he desires. So, as you readily see, Mr. Steinmetz desires an explosion; he does not apparently want a fuse that goes quietly and nicely and properly.

Now in regard to what fuses will do and where they will do it and how they will do it, if you will kindly refer to my paper, I think it is at page 101, "it is, however, only necessary for a protective device" (fuse or otherwise) "to accomplish satisfactory results on the particular service in connection with which it is used." When a protective device is constructed to operate in a trolley car, for instance, or to operate at the end of a long-service line, protecting a converter or supplying a house-service, it is not supposed, and it is not necessary that that fuse should be capable of being thrown across the bus of a 10,000-K.W. station to stand the short-circuit there, as nobody would want to pay for a fuse for a converter service that would stand the latter service which in practice it would never be called upon to perform. Fuses to stand the excessively strong blows can be constructed and will operate without explosion. It is, however, essential to carefully consider size and arrangement. Some of the sizes that Mr. Steinmetz has named may be rather large, but I feel confident, from tests which I have made and from the experience in that direction I have had, that the energy thrown into a fuse of the type that I have shown you can be choked off and more or less absorbed and dissipated without bursting the tube, without exterior manifestation and without tearing the cable, the dynamo or the flywheel to pieces. If Mr. Steinmetz has any protective condition or proposition that he would like to have me try on, I stand ready at any time to take it up, and it simply remains for Mr. Steinmetz to furnish the apparatus. The test can be very carefully conducted by trying the fuse first under conditions of minor severity and gradually increasing the abnormal conditions. I do not expect Mr. Steinmetz to take a

large generator and short-circuit a fuse across it before he knows exactly what it will do.

Mr. Steinmetz has said the capacity of the generator affects the device. I have stated that previously in my paper in the section on the general principles of excess-current protection, which I did not read. I discussed the generalities quite fully, and stated that too much stress cannot be laid upon the size of the generating capacity, the character of the generating capacity, the distance from the generating capacity at which the fuse is placed and operated, the character of the circuit and its impedance. I stated that the effect of a short-circuit or any abnormal current condition simply depends on the decreased impedance, assuming that the generating capacity remains at normal or rises in potential. Certainly where we have generating capacities that go down, the proposition is comparatively simple, and that is the point I tried to bring out—that too much stress has been laid upon the mere voltage feature. A 2500-volt circuit does not necessarily require an abnormally long fuse. It may be possible to use a shorter fuse than on a lower-voltage circuit where the generator and other conditions test the protective device more severely. The short-circuit tests of fuses, which Mr. Steinmetz says are valueless, because they simply can be specialized and not generalized, I cannot quite agree with. While it is a fact that there are overload conditions, a great many of which Mr. Steinmetz has named, that are more severe than a short-circuit test, yet it must be acknowledged that a device that can stand an instantaneous blow of the enormous amount of energy that must be instantaneously absorbed on short-circuit is certainly the device that *per se* will possibly hold a pretty good overload under similar service conditions. Fuses should be built to meet conditions and not necessarily voltages. Similar conditions of energy rupture may exist at different voltages. I have absolutely short-circuited a fuse having a continuous running capacity of 600 amperes, on one of the largest 500-volt street railway systems in this country, with enormous feeders, at a distance of only half a mile from the station, the station being one of two connected into the network of feeding conductors. I would also refer Mr. Steinmetz to page 105, where he will find a consideration of the gradual break.

In regard to Mr. Wilson's and Mr. Mailloux's remarks I will first take up the matter of trusting to the attendant to open the circuit instead of to a simple automatic device. Such trusting to the attendant may serve very well under conditions of gradual overload, but it does not take care of the short circuit. The short-circuit rush is quicker than the attendant, even though he may be lightning-like in his movements. A device which by means of a current relay notifies the attendant when to pull his switch or operate his regulator or to do something to take off some of the load is excellent; but there exists no such means of

indicating to the attendant quickly enough the fact that somebody has dropped a screwdriver across the bus-bars on the switchboard or panel, or the occurrence of an equally severe abnormal condition. It would be better to have the device automatic. Simpler and safer automatic apparatus than a properly designed enclosed fuse is almost impossible.

In regard to the instantaneous operation of fuses on overloads, I want to draw the attention of Mr. Steinmetz and Mr. Mailloux to the curve shown on page 109, which clearly demonstrates that when the overload on the fuse becomes excessive, and only at that time, does the fuse operate almost instantaneously. Should the overload be a gradual one there is ample time for the attendant, who should be at the switchboard to notice that his ammeter is reading higher than it ought to and pull his switch or operate the generator rheostat to lower the voltage, even perhaps before the fuse is blown, if the fuse is properly designed for that condition. Let the ammeter serve as the excess indicator. I think it is an absolute fallacy to put in a fuse to act as a protective device which will continuously carry 100 or 50 per cent. above the capacity that the machine is supposed to stand, for some length of time, but beyond which it is injured. If the fuse carries it continuously it is not a protector for that machine or other device if the relations are as stated.

MR. MAILLOUX:—Does not pulling the switch reduce the E. M. F.?

MR. SACHS:—It is by no means desirable to instantaneously throw off the entire load carried by a large generating unit for various obvious and previously mentioned reasons. Such instantaneous break occurs when a switch is quickly opened, but the opening of a fuse of the character described is of another nature. Reference has already been made to the gradual increase in resistance of the structure between the fuse terminals which necessarily results in a more or less gradual break and buffing effect.

In substantiation I may refer to the tests of the indicator wire without the fuse and the action of the complete fuse with indicator (see page 107). It can readily be demonstrated that the fuse, at the moment when it starts to go, does not let go with an instantaneous drop, but with a gradual slide. The gradual break certainly must occur in a very short time-interval, but whatever that time-interval may be it is sufficient to ease the current-breaking effect far more than if it had been instantaneously choked off as in the case of electro-magnetic switch devices.

The advantages of a time-interval device such as a fuse for motor service need not be gone into here. The relative advantages of electro-magnetic devices, which are instantaneous, and time-interval devices such as fuses, as applied to motor service, are well understood. I believe it is universally acknowledged that for the protection of the motor and for the service that it

performs, except in certain particular conditions, where the machine driven has no time-interval overload capacity—such as a press, for instance—that a time-interval device is superior.

In regard to Mr. Wirt's discussion I must say that I certainly cannot agree with any rating of any electrical device, whether it be a fuse or circuit-breaker or dynamo or motor or anything, except at its continuous, constant running capacity. If we have a motor that will run at two-horse-power continuously why should we rate it at one? I do not believe that motor or dynamo manufacturers or manufacturers of any electrical devices are willing to half or three-quarter-rate their electrical devices, yet the liberal fusemaker tells us that he is willing to rate his fuses at only three-quarters of what they actually carry. In other words, we are getting more than we want. But getting more than we want under such conditions simply means that the generating apparatus or the motor or the wire may also get more than it wants or ought to have.

The matter of destroying 100-ampere fuses on a rotary converter under the conditions that Mr. Wirt has mentioned is simply a condition as I have already considered. Any apparatus or device, whether a fuse or anything else, should be built to meet some particular condition or service. In the case of a fuse or similar device this service involves the opening of an abnormal energy condition impressed upon it. It should not be expected to open several times its intended capacity. The 100-ampere fuses tested were apparently not intended to serve at the particular conditions of the test. But that by no means implies that similar fuses intended for such service are not available. It is simply necessary to provide different arrangements of the parts to produce the desired result. Mr. Wirt should not expect a fuse intended for some particular service to operate under any other. If Mr. Wirt will inform me of the conditions to be met, not only the voltage, I will guarantee to furnish him with a fuse that will operate satisfactorily.

The matter of whether expensive fuses are the proper protective device on a railway system, particularly in the cars, is a matter that I am especially interested in. It is a matter that I have given quite some attention to, and the fact remains that to-day we are able to sell in quite some quantities protective devices that cost three, four and five dollars a piece, whereas an ordinary open wire to perform the same service would cost perhaps five cents. Now that is an actual fact, and it is an object lesson, I think, that may indicate to Mr. Wirt the fact that the street railway manager is not simply looking for the cheapest device, but he is looking for the device which will permit him to operate his road most safely and satisfactorily. Mr. Wirt must remember that the first cost of an enclosed fuse is by no means the cost of using it. The refilling cost of the casing is not by any means an abnormal figure comparatively.

Now, with regard to Mr. Downes' statement and also Mr. Henshaw's statement in regard to the details of the construction of the fuses, I want to say first that the principles upon which the fuse which I have shown you this evening is based are peculiar. It has been a matter of a great deal of experimentation to arrive at the exact combination of elements that produces the present results. You might put, for instance, a silicious powder in a tube, thread a fuse wire through and produce a combination, but such a combination would produce exactly what Mr. Henshaw has said in regard to the formation of an envelope or a tube of silicate. The mere formation of a combination is not sufficient to produce an operative enclosed fuse. The character and form of the resulting commingling of the elements must be most carefully determined. This has already been emphasized in the paper.

Whether the blowing of the fuse results in a combination of the oxidized vapors and the filling material, or whatever other forms of the vapors may combine with the material, does not enter into the question at all. The fact is, that metallic vapors will oxidize, and the fact also remains that such metallic oxides will combine with non-metallic materials. In the matter of oxidation of an inclosed fuse strip that is surrounded by air, Mr. Downes must acknowledge that such a fuse strip enclosed in an air envelope is supplied and resupplied with air during the successive heating and cooling of the fuse. When the interior chamber is heated, the gases expand and the air is forced out. When the fuse cools, fresh air is forced in. So you are getting a continuous supply of air on the inside of the tube. I need not discuss the advantages of an oxide envelope formed around lead and tin fuse wires. That feature has been discussed in previous papers, and it is universally acknowledged to be a disadvantage.

The blowing of the 2500-volt fuse seems to have aroused some discussion; also the word lag. When I spoke of lag I meant the lagging of impressed energy or heat-producing effect. Whether this lag was due to the conditions in the dynamo or circuit matters not.

Mr. Downes has stated his experience in regard to the effect of the wire-surrounding environment on the carrying capacity of the fuse. This result will appear entirely obvious when the varying heat conductivities and capacities of the various materials which may be used as fillings are considered. The paper has made note of this feature as a particularly important one in connection with the design and construction of enclosed fuses. (See page 103.) Mr. Downes' idea in regard to the action of the strip shown in Fig. 16 is to a certain extent correct. It is quite true that the active material is a poor heat-conductor and permits the more rapid heating of the strip around which it is placed. This fact alone would, however, only result in a sim-

ilar condition to that described in the test on page 95, in which the holding of the molten fuse wire in metallic continuity, when encased in an ordinary environment, was clearly demonstrated.

Fig. 16, however, shows that the wire in the center was entirely molten, but the rupture occurred at a point where, after the wire had attained a molten condition it was no longer permitted to remain in continuity, owing to the action of the peculiar environment at that point.

It is probably unnecessary to refute at length any statements relative to the accuracy(?) of open fuses. The opening chapters of the paper generally consider this proposition, and I believe the premises taken have good foundations.

In concluding the discussion I will ask your pardon in repeating the spirit of a former statement. Properly designed enclosed fuses can be constructed to open excess-current conditions in a manner unequalled by any other present form of protective device.

PROF. R. A. FESSENDEN:—I have an item of new business to bring before the meeting. A motion has been drawn up by several gentlemen who are interested in electrical units, as follows:

Moved, That the Committee on Units and Standards be requested to investigate and report at the ensuing meeting in regard to the advisability of the following:

1. The giving of names to the absolute units of the electrostatic and electromagnetic systems.
2. The denotations, by means of prefixes, of multiples of such units.
3. The rationalization of the present system by means of taking the absolute unit of magnetism as equal to the present magnetic line, and the absolute unit of difference of magnetic potential as equal to the present absolute unit of current-turn.
4. The advisability of taking up any or all of the above matters at the Congress to be held in Paris this year.

I have received the following letter from Prof. Elihu Thomson, seconding the motion:

SWAMPSCOTT, Mass., March 9, 1900.

TO THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS:

I desire to second the motion of Prof. R. A. Fessenden to request the Committee on Units and Standards to investigate and report upon the subjects mentioned by him in the accompanying motion.

ELIHU THOMSON.

It will not be necessary to have any discussion about this at present, I suppose, as it is late and as it is a matter for a committee to investigate.

It was voted that the resolution be referred to the Committee on Units and Standards, and the meeting adjourned.

[COMMUNICATED AFTER ADJOURNMENT BY HOWARD R. SARGENT.]

From the reading of the paper, experiments and discussion following, it would seem to me that the enclosed fuse has a large field for 250-volt or 500-volt work up to 50 amperes. This would cover the wiring of buildings, protection of small motors, etc. For larger work, especially station work, it would seem from the discussion and remarks of central station men present that the field for the enclosed fuse would be very small, on account of the cost, bulk and uncertainty of operation.

Mr. Sachs claims that a fuse can be made which will entirely enclose the arc and explosion, no matter how severe the conditions, but he does not state what the size of such a device would be. From tests which I have observed it would seem that the size must be excessive.

In connection with this, should a fuse of this type be built to stand the most severe conditions which can be imposed upon it, or should it be built to take care of a short-circuit such as would be obtained at a distance from the central station?

Referring to Mr. Sachs' remarks concerning the metal of the fuse itself, we presume, of course, that the reference to the oxidation of lead-tin fuse wires concerns only those commercial fuse wires which are made of practically pure lead. A lead-tin fuse wire which is very rich in tin will not oxidize under ordinary conditions.

From the table given on page 109 it would seem that a very objectionable feature of the solid-packed fuses is the variety of diameters and lengths. Each different length and in all probability each diameter would require a separate fuse block, and a central station manager or supply house would be obliged to carry an enormous stock, and in time of an emergency would probably find that the particular size desired was not at hand.

In the discussion Mr. Sachs stated that with the shunt indicating fuse there was an appreciable time interval in the rupture of the circuit. Does this not emphasize the fact that the indicating fuse blows after the main fuse has gone, and that the shunt fuse therefore practically aids in rupturing the arc and also forms a menace to any inflammable material near the cut-out.

During the discussion Mr. Downes stated that in order to take care of the more severe conditions, fuses of the enclosed type require vents, and an examination of the lecturer's samples shows that he has embodied this feature. Where then is the line drawn between an enclosed fuse and an open fuse? If these vents are to be placed in the ends of the fuses, are the enclosed fuses not as bad in certain ways as the open type? The public know enough to keep away from an open fuse, but it seems to me that a fuse as described above would resemble an ambush and lead to serious personal injury, if not to serious conflagration.

In connection with this subject I should like to mention a recent test which I had the pleasure of witnessing.

Vulcanized fibre tubes $\frac{3}{16}''$ thick, 5″ long, $\frac{1}{2}''$ inside diameter were taken, and solid plugs were riveted in the ends so that air chambers $\frac{3}{8}''$, 1″, $1\frac{1}{2}''$ and 2″ long were formed. After 30-amp. fuse wire had been inserted through the chambers, caps were riveted on the ends. These fuses were short-circuited close to two 400-K.W. 250-V rotary converters running in multiple.

The first and second fuses were totally destroyed, the third fuse had the plugs blown out, and the fourth fuse was left practically intact. This would seem to show that it is a valuable feature to have a large air space for the vapors formed and expansion which takes place; also that the larger body of air tends to form a cushion for the explosion. This experiment is merely mentioned on account of its being a rather peculiar one, and is not, of course, conclusive.

Schenectady, N. Y., March 30, 1900.

[COMMUNICATED AFTER ADJOURNMENT BY L. W. DOWNES.]

I can hardly agree with Mr. Steinmetz's assertion that short-circuit tests of fuses are not only valueless but misleading, for, while I believe that they do not in themselves decide absolutely the value of that fuse as a protective device, they do unquestionably determine its effectiveness under conditions which are not at all common in daily commercial practice.

Assuredly, nobody can claim that short circuits, particularly in direct current lighting and power systems, are of rare occurrence. Quite the contrary, and a protective device to come at all within the requirements of commercial service must certainly be capable of handling such short circuits.

I heartily second Mr. Sachs' assumption in this matter, that the fuse must be tested under practical conditions and not under abnormal ones, or, in other words, the fuse should be designed for the service for which it is intended, and it is not all reasonable to make a test, in the manner suggested by Mr. Steinmetz, using a synchronous motor. The conditions there that he described, viz., of heavy lagging current and the doubling of the voltage, are abnormal for any circuits other than those upon which such particular test is made. We certainly do not get such conditions in direct-current electric lighting. We certainly do not get such conditions for transformer protection. We certainly do not get such conditions in direct-current power work. Consequently, wherefore is it desirable that the fuse, which is used on these various systems, should be so constructed as to meet abnormal conditions which can never possibly occur on the systems for which they are specifically intended? On the contrary, fuses used for synchronous motor work must assuredly be designed to meet the peculiar conditions of the service, and it is quite within the possibility of the enclosed type of fuse, in my

opinion, to construct them, so that they will operate satisfactorily, provided the current capacity called for is not too great.

I believe that all tests of fuses should be carried on under conditions which as nearly as possible approximate those which are met with in commercial service, and it is the practice in our laboratory to carry on tests in that manner. All fuses are first tested for continuous load at normal atmospheric temperature, the duration of such test being sufficient to determine absolutely that the carrying capacity of the fuse is that at which it is rated. The operation of the fuse under conditions of overload is then determined, starting with comparatively small overloads from 25% up to several hundred per cent., the current being adjusted previously to a definite value, with a fuse in shunt, and the overload being then suddenly thrown upon the fuse. Finally, the operation of the fuse under short-circuit conditions, precisely the same as those that we have to meet in practice, concludes the test on that particular type.

We, moreover, carefully avoid testing a fuse which is intended for use on 110 or 250-volt service on a circuit of either higher or lower potential, which same applies to all the fuses that we manufacture. This, I believe, you will agree with me is a reasonable and accurate method of determination, and the results of the operation of our fuses in practice have certainly sustained us in this position.

The limiting conditions, in my opinion, of this enclosed type of fuse are a matter more of cost than anything else, since with increased capacity comes an increase of cost, which is by no means proportional.

I feel that Mr. Sachs has fallen into the same mistake in his comparative test, referred to on page 112. He has attempted to make comparison between the solid-packed type of fuse and one of our type, without knowing definitely that they were designed to meet the same conditions. Such a test is obviously at fault, and the only way in which determinations can be made, which would definitely answer this question, would be by comparing fuses which were intended to meet some particular condition or class of service.

This statement of Mr. Sachs is on the same line of reasoning as is his comparison of the short-circuit test of the 2500-volt alternating and the 500-volt direct current generators. He has stated in this discussion that he intended to use the term "lagging of the current-rush" to mean diminution of the energy.

I fail to see wherein the word "lagging" can be used to mean diminution, and in the case referred to the results were unquestionably brought about not by a lagging of the current, but by an actual decrease in the current, due, as Mr. Steinmetz has so clearly pointed out, to the actual momentary wiping out of the voltage across the circuit, conditions which were clearly defined by experiments, which I have referred to before to-night.

I have given a great deal of study to both the solid-packed and the air-drum type of fuse, and my observations have all shown that a degree of sensitiveness and accuracy can be secured in the air-drum type that cannot be approached by *any* form of the solid-packed type of fuse, and, moreover, these tests can be substantiated at any time.

Providence, March 31, 1900.

[Communicated After Adjournment by the Author.]

In reply to communications of Messrs. Sargent and Downes.

I believe, in justice to myself, that a few final remarks answering those communicated by Messrs. Sargent and Downes, may be warranted, in view of the premises taken by both of these gentlemen. Mr. Sargent states that it would seem to him "that the enclosed fuse has a large field for 250-volt, or 500-volt work, up to 50 amperes. * * * for larger work, especially station work it would seem from the discussion and remarks of central station men present, that the field for the enclosed fuse would be very small, on account of the cost, bulk, and uncertainty of operation."

If the gentleman had taken the trouble to inform himself more fully in regard to the actual service being performed by fuses of my design, not only in ratings up to 50 amperes, but in current capacities up to 600 amperes, and above, he would probably change his opinion as to the practicability of large fuses of this type. The matter of cost is governed entirely by the character of the service performed, and the necessity for such service.

On the question of bulk, Mr. Sargent certainly cannot say that a fuse capable of running continuously at 600 amperes on 500 volts and operating without arc under any excess current condition, and with a maintenance of its accuracy, is a bulky device when the completed fuse tube with its terminals measures only two and one-half inches in diameter by ten inches long. An 800-ampere fuse for 500-volt services is only three inches in diameter and about ten inches long. If Mr. Sargent will kindly refer to the table in the latter portion of my paper, he will find that a complete list of dimensions is given of the various sizes of fuses.

Why the enclosed fuse should be accused of uncertainty of action in view of the statements made in my paper, and the vast number of these devices in daily use, I cannot understand. Mr. Sargent has absolutely no reason for any such statements. If he has tested fuses of my design he has probably tested them under conditions for which they were not intended. I can but again repeat that enclosed fuses can be built to do all that Mr. Sargent

reasonably desires without any uncertainty of operation, and that I stand ready to furnish him with such fuses.

The objection made to enclosed fuses, based on the fact that fuses of different current ratings, and for use on different voltages would require different tube diameters and lengths, is a very old one, and scarcely can be considered as a very weighty one. One might as well say that owing to the different arrangement of circuits, and the different conditions and voltages at which they operate, a large variety of wire sizes must be kept in stock by the supply house, but it would be very much better if the supply house, simply kept one size in stock. I hardly believe that this arrangement would meet the approval of Mr. Sargent, although it is practically analogous to the fuse case.

It is scarcely necessary to again take up the action of the indicator wire, as this has been very fully considered in the paper. Mr. Sargent is, however, entirely incorrect in his assumption that the shunt fuse (the indicator) "practically aids in rupturing the arc, and also forms a menace to any inflammable material near the cutout." The indicator wire does not rupture until the resistance of the interior fuse has been increased, due to its disruption, to a point where the conductivity of the two paths—that is, the interior wire and the exterior indicator,—are almost equal. Then the current, passing through the shunt fuse, is sufficient to rupture it, or perhaps even before this condition is arrived at. The indicator wire then ruptures almost instantly, but the interior wire is still not absolutely ruptured and, as has been stated in the paper, the final break occurs inside of the tube, and not outside. I can scarcely see why Mr. Sargent should at all doubt this, after having seen the experiments and read my paper.

I would request that Mr. Sargent, however, should read the discussion, both at New York and Chicago, and probably obtain some further idea of the action of this indicator. I can only say to Mr. Sargent in regard to the ignition of inflammable material by the indicator wire, that the test made at the Chicago meeting, and mentioned in the Chicago discussion will probably do much to clear this point in his mind. The placing of vents at the end of fuse tubes is not for the purpose of permitting an arc display at these ends, but is simply intended to act as an outlet for some of the excess gases which cannot be taken care of in combination. To question whether the enclosed fuses are as bad in certain ways as the open type is scarcely worthy of serious consideration.

I am pleased to see that Mr. Downes agrees with me in the position that I have taken in building enclosed fuses to meet conditions of electrical service. My experience has clarly demonstrated that this is the correct basis. The matter has been so well discussed that nothing further is needed to establish the fact that a fuse constructed to operate satisfactorily on a trolley car, is not necessarily a poor fuse because it does not operate as well when

short-circuited at the bus-bars with 10,000 or 20,000 K.W. in back of it.

I must also agree with Mr. Downes in saying that the limiting conditions governing the operation of enclosed fuses is the matter of cost, which, in the very large sizes, rises disproportionately.

I will not discuss in detail the matter of comparative tests between the solid packed type of fuse of my construction, and the air-space type any more than to say that the record of the tests shown in the paper clearly demonstrates that the matter of hot and cold overload time ratio is in both fuses governed by the same general features.

Finally, I must again take exception to Mr. Downes' statement: "that a degree of sensitiveness and accuracy can be secured in the air drum type that cannot be approached by any form of the solid packed type of fuse, and moreover these tests can be substantiated at any time." I regret to say that the substantiation of such comparative tests is a matter which I am only too eager to do all within my power to bring to a definite head; but have in the past found no reciprocation of this desire. I have not been able to find any air-space fuse that was not beset with all the peculiar features of the solid packed type, and in addition, a number of others which made it by all means inferior to the construction of my design, in which the air-space is entirely omitted. Mr. Downes will find me decidedly agreeable whenever he is ready, to demonstrate the comparative merits of air drum and solid packed fuses, further and beyond the matter already included in my paper.

DISCUSSION AT CHICAGO, APRIL 27TH, 1900.

THE CHAIRMAN (MR. R. H. PIERCE):—Gentlemen, I am sure we feel that Mr. Sachs has conferred a favor upon all of us who are interested in this subject by the able presentation of his paper, and that his practical demonstrations have been most interesting and instructive.

We have a number of gentlemen here this evening who are interested in this subject and who have carried on experiments, and some of them possibly have theories to advance.

We would like to hear from Professor Jackson.

PROF. D. C. JACKSON:—Gentlemen, I was not aware when I came to town that there was a meeting of this kind on hand. I want to say, however, that the society is to be congratulated on having Mr. Sachs' paper presented to it. It is evident that Mr. Sachs has eliminated the ordinary errors of experiment with respect to fuses in carrying on his work. I have not carried on

a great many experiments in the laboratory with respect to fuses, though I have had a good deal of experience with their use in circuits. Several years ago I was, however, called upon by a manufacturer to give an opinion with regard to a certain fuse alloy, especially with respect to certain points. I made a test of the alloy and gave my opinion, which was rather different from the opinion which was held with respect to similar alloys by many other people, and rather different from the results that had been presented in some papers that might be considered authoritative. I thus became somewhat interested in the matter, and at the time took advantage of the fact that one of my students was about to choose a subject for his "graduating thesis." He was a very reliable young man, with keen intellect and considerable initiative, and I persuaded him to undertake an investigation of certain features of fuse wires. His results are briefly presented in vol. xi, p. 430, of the INSTITUTE TRANSACTIONS.

In the process of doing this he looked up the basis of a great deal of the literature and brought it to my attention in a way that I perhaps would never have undertaken myself, and he found that a good deal of our literature up to that time was in error, due to the fact that the errors of experiment had not been avoided; as, for instance, a great deal of the experimenting which had been carried on with respect to the change of resistance of the fuse when in use or the change of melting point of the fuse when in use—and when I say melting point I mean with respect to the amount of current carried—was replete with errors. These errors were due to the fact that the environment of the fuses under test had not been taken into account. Consequently, in a few hours a fuse might appear to show a higher resistance than its initial value or perhaps the fuse would melt at a lower current than appeared to be sufficient to melt it under similar conditions at first. But these apparent changes were false and were due largely to the effects of the environment, which had not been eliminated. You will find that some authoritative papers of a few years since are all in error on these grounds. I think Mr. Sachs has appreciated the errors of experiment and produced a successful result partially because he has eliminated those errors.

THE CHAIRMAN:—We have with us Mr. Varney, whose experience in the laboratory of the Chicago Board of Underwriters has undoubtedly brought him in contact with the recent developments in this art. We would be pleased to hear from him.

MR. T. VARNEY:—I think it would be well to explain that we have another gentleman present to-night who has done that work, and he would be much better able to discuss his results in that direction than I. Mr. Glover, of the laboratory, has, I believe, conducted a considerable investigation of the fuse, and I think he would be better able to tell you about that than I would. The work that I have had to do has been more especially inspection work in the towns of the central states. In the small

towns they are hardly educated yet to the point of enclosed fuses, but I venture to say if they were, it would result in a very material decrease in the fire risk. In many of the small towns they have some crude types of fuse, in some instances perhaps wooden fuse plugs and things of that sort. Undoubtedly this would be a great improvement over most of the fuses in use.

MR. B. H. GLOVER:—Mr. Chairman, I appreciate very greatly the privilege of being here this evening and the privilege of having the floor. This paper has been one of great interest to me, because the subject of fuses has been brought to my attention in so many different forms and under different conditions that I am glad to know of a device which apparently has overcome most of the defects inherent in fuse devices.

There are one or two points that I noted in this paper which I would like to speak about. One very important point mentioned on page 110 is that in the manufacture of these fuses every effort was made to determine the accuracy and reliability of the fuse by actual test. I find that it is a great fault with the manufacturer that he does not fully understand perhaps his own product. For instance, I know of a manufacturer who has no electric current in his factory, and in making fuse plugs or rheostats, if he ever makes a test, he has to put a number in his pocket and go three or four miles to the village electric light plant and connect up with the station meters and possibly get some results.

The position of the underwriter at the present is, if possible, to do away with the use of the varied forms of open link cut-outs. They have proved their unreliability, but perhaps have served their purpose well in bringing the electrical engineer to a position where he can appreciate the necessity for a more perfect device. The introduction of the enclosed fuse from the standpoint of the fire underwriter must be encouraging and gratifying. The effort should be made, if possible, to standardize these devices, and in conversation with Mr. Sachs I was very much pleased to find that he had adopted the same length, I believe, and space-distances, with his fuses and bases as have been already introduced by some of the other manufacturers of enclosed fuses. If a standard can be outlined for these devices, the various manufacturers can then use their ingenuity and wisdom in perfecting the details of the device. I note that with some of these bases it is possible for the fuse to jar or slide out of position, which is a slight mechanical defect which could be very readily remedied and would make the device more reliable perhaps under the various conditions it is liable to meet with in service.

There are one or two questions that I would like to ask, if I may have the privilege, as to the possible effect of the shunt wire indicating device, especially on the smaller fuses; whether the rating of the fuse takes into consideration the very slight, but perhaps appreciable, carrying capacity of this shunt wire? And also, as to the compounding of the active environment,

whether it is possible under certain conditions to have this environment separate out so that the active material would not be brought into active connection with the whole fuse wire?

MR. SACHS:—In answering Professor Jackson first, I do not want by any means to have it considered that this concludes the discussion, because I hope it does not. I must say that amongst the literature on fuses, that the paper to which Professor Jackson referred is one of the shining lights, because it seemed to have first brought out the feature that the professor mentions, namely, the fact that the fuse for its accuracy and for its action almost entirely depends upon the environment. Now, by environment I not only mean the material itself, but the character and the form and also the condition of the environment. I must, however, also add that while this paper possesses peculiar merit on that issue alone, and even if it possessed none other it would be striking in view of the fact that so many writers on the question of fuses have not sufficiently grasped the subject at all.

In general electrical practice fuses have been regarded more as a necessary makeshift than as an accurate, safe and reliable protective appliance. Wiremen and others, who handle these devices, have used them on the basis that if what is required is not at hand, use anything that is, and put it in.

Now, in taking up the question of the fuse protective device from an engineering standpoint, and endeavoring to attack the problem from an actually scientific basis, it may seem that perhaps small fish have been fried. But that is not the fact; because the fuse protective device is a universally applicable and essential apparatus, whose use is increasing instead of decreasing. The demand to-day is for a protective device that shall be safe and accurate. Now, if the old fuse is not, something else must be produced.

Mr. Glover speaks of standardizing the fuse of the enclosed type, and certainly nobody is more desirous of standardization than the manufacturer, for the simple reason that if there is one standard type of receiving device used for the reception of these fuses, why then any one manufacturer can go into any other manufacturer's block and sell fuses where the other fellow previously sold them. Specialization for individual custom is the thorn in the side of economical manufacture. I know that I for one am highly desirous of standardization in this direction. The fact still remains that some fuses are capable of being placed where others cannot be placed; and while it is probably fairly possible to adopt common lengths, it may be essential to vary detail construction in exactly the fashion that Mr. Glover has mentioned.

The condition that Mr. Glover mentions in connection with the jarring of the fuse, refers, I presume, particularly to the snap contact block, in one or two sizes, in which it is possible to shove the fuse lengthwise. That is to be remedied. We have found,

however, no objection to the jarring, although a number of these blocks have been in position. It is scarcely possible to sufficiently jar such a cut-out, as ordinarily installed, to produce this condition. The shunt resistance to which Mr. Glover's other inquiry refers is not at all taken into consideration in rating the fuse, owing to the very high resistance of the shunt indicating wire. I have forgotten the exact resistance of the wire per inch, but it is very high. I believe a six-inch piece measures something like 15 or 20 ohms. You will readily appreciate, therefore, that when such resistance in its proportionate length to the size of the fuse on which it is used is shunted by such extremely low resistance of the high conductivity main fuse, that the current is shunted out of the high-resistance conductor and passes practically entirely through the fuse conductor itself; so that under normal conditions the percentage of current flowing through the indicating conductor is a negligible percentage of the current carried by the complete fuse. In fact, it is not taken into consideration in rating any of these fuses. On very delicate fuses of quite some resistance, where the carrying capacity is a small fraction of an ampere, an indicator wire of the type I have here cannot be used.

It seems rather strange that it was necessary to go through all this experience with arcing fuses before it was actually possible to get the electrical fraternity to appreciate the necessity of a protective device that eliminated the fire hazard. Back in 1890 I had the greatest difficulty in trying to interest people in this device. It could not be done. One gentleman said to me, as I often hear to-day, "What is the use of putting the fuse in a tube when it works without a tube?" And I even find to-day that appreciation on the part of the user will come slowly, but I believe when it does it surely will stay.

As Mr. Glover says, the underwriters will necessarily always favor a device that adds to the safety of an electrical installation, and I believe, after the electrical contractor and the user has discovered the fact that it is really cheaper to get rid of this fire hazard and pay a little more money for his fuse, that the enclosed fuse will become universal.

I note that Mr. Cutler is present this evening. Mr. Cutler entered into the discussion about a year or two ago on the enclosed fuse, and I know we would all be pleased to hear from him.

MR. H. H. CUTLER:—Mr. Chairman, I would be glad to say a few words if I can assist matters any. I might start by saying that three years ago, when the enclosed fuses were put on the market in practical shape, I was very much interested in the question. It was just what I had been looking for, and I received it with open arms. I wanted it for a peculiar use. It might be interesting to state what that was. I had been manufacturing, and still am, as most of you know, a device for starting motors, and on a great many of them I put what is generally known as an overload

attachment. This overload attachment I have always known was of no earthly use as a circuit-breaker. But most people think to-day that it is a circuit-breaker. It is only of use for normal overload. I wanted something to make a complete device to get on the market with. I had had enough experience to become disgusted with open fuses a good many years ago, and when the enclosed fuse came out I put it on my device and I went so far as to advocate its use in my catalogue. I think it might be interesting to read just what I say about this enclosed fuse in my catalogue. I tore out a page on my way down here. "The prices given on page 21 of our catalogue include the furnishing of a pair of enclosed fuses, rated to blow at a current twice as great as the ampere rating of the motor for which the starting rheostat is furnished. Our overload attachment will satisfactorily protect the motor from abnormal currents up to 50% overload, according to the position at which it is set. Should a short-circuit occur or a very heavy load be suddenly thrown upon the motor, the fuses can be absolutely depended upon to blow. This they will do with absolutely no arcing whatever, thereby constituting a distinct advantage as a fire risk over the use of a circuit-breaker, which draws a long, flaming arc when opening a circuit carrying an abnormal current. The enclosed fuses have no mechanism to get out of order or parts which can be improperly adjusted by uninformed persons. They will not rust or deteriorate, are unaffected by moisture, temperature and other external conditions, and will be found ready to act at any time without requiring the slightest attention. By using these enclosed fuses in connection with our overload attachment, the fuses will never be called upon to act, except in cases of accidental short-circuits. Both the motor and the starting rheostat are as perfectly protected as it is possible to have them."

I thus constituted myself an advertising agent for the manufacture of enclosed fuses, for which I did not get a cent. I am simply doing it in the interests of good engineering, and it helps our apparatus; it helps its reputation. However, you know that most people will not pay anything for it. As a matter of fact, not 10% of our apparatus goes out with enclosed fuses on it, because people won't pay 20 or 40 cents more on a rheostat that costs them all the way from $10 to $50. At the same time, I asked my order clerk to-day on coming in about how much money we were spending for enclosed fuses that we gave away to people, and I found it was costing us about $50 a month to advance this cause of good engineering.

I might say after I adopted it myself I took an agency and wanted to help the thing along, and I tried to introduce them among my acquaintances here in Chicago. One of the first persons I called upon was my friend Pierce here. I showed him one of the fuses, and he said: "It looks like a pretty good thing. Just leave a few and we will try them." That is the last I ever

heard of it. That was two years ago. I took them out and showed them to a dozen people and had about the same result. I found that the only way I could get rid of them was to give them away. Nobody would pay for them.

There was one thing I noticed here—the difference between the merits of the solid-packed fuse and the fuse with an air space. Now, from the description which Mr. Sachs gave us I am not clear whether his fuse has an air chamber or not, and I would like to have him answer that. But I noticed that Mr. Sachs himself stated an objection to the solid-packed fuse, namely, that the metal would stay in a melted condition and thereby create an arc. What I have always understood as the advantage of the air space was to prevent this molten metal from allowing the current to continue to flow. It also seemed to me, as I understood the paper, that the reason the solid-packed fuse blew before the fuse with the air chamber was due more to the character of the metal which Mr. Sachs used in his fuse than it was to the existence of the air chamber. That point I am not clear on.

I also noticed another thing, that you have got a very nice name for this fuse, a "no-arc" fuse, but at the same time it does arc. Now, the enclosed fuse possesses the distinguishing advantage of having absolutely no arc, and while in a great many cases, of course, this little arc with the wire is no objection, in some cases it would be, but it destroys the theory of the thing. It is so pretty to say a fuse blows when you don't know it.

MR. SACHS:—That is just exactly the point, it is too pretty. It is pretty to the extent that you don't know it; but you want to know it.

MR. CUTLER:—Well, I think the indicator might be an advantage, but I think some people wouldn't want it if they were going to use it in a flour mill or anything of that kind.

MR. SACHS:—You don't have to use the indicator, you know, if you don't want it. The sole use of these fuses is not confined to flour mills or powder magazines.

MR. CUTLER:—No, you don't have to use it. But it is not a "no-arc" fuse with that indicator on.

MR. SACHS:—If Mr. Cutler will carefully read my paper he will find that the action causing the disruption of the indicator can by no means be considered as resulting in an arc. In order, however, to thoroughly convince Mr. Cutler I will blow several fuses with cotton lint packed around them. I hope Mr. Cutler will at least be partially satisfied with these tests.

MR. CUTLER:—I heard you speak very favorably of the underwriters just now. I think a good deal of the underwriters sometimes, but sometimes I get very much discouraged, which, in the case of these articles that you referred to just now, was due entirely to the obstinacy of the underwriters in New York City. Possibly, very few people knew what made me arrive at this

inquiry. It came about by a law that was passed in New York City which required every person who installed a motor to put on a circuit-breaker. I was very much disgusted with that law because I was not making circuit-breakers. It came about through a test started under the auspices of the Edison Illuminating Company, and all the manufacturers exhibited starters in, and an enclosed fuse was suggested at that time. Now, the chief of the Electrical Department was present when this circuit-breaker was presented but took no interest whatever in this enclosed fuse, which acted perfectly; there was no fire risk whatever, and it showed by the test that was made to be more depended upon than any circuit-breaker that was exhibited. Nevertheless, that rule was passed, that it didn't make any difference whether you used an enclosed fuse, the circuit-breaker had to be put on. That is one thing the underwriters do sometimes.

Now, I have always been a strong advocate of fuses, and, as some of you know, I have put them in places where other people think they are worse than useless. For instance, I noticed that you mentioned the fact that the fuse could not be used in the place of circuit-breakers on account of the time taken to replace them. Now, of course, that is very easily overcome by having several fuses with switches to throw them on. I have found also that they can be used on switchboards, and they can be used on railway feeders, provided you get good circuit fuses up to a thousand or more amperes, though up to the present time I have never seen one. But if you got them you would have a very great advantage over the present circuit-breaker that is being used, namely, that nine times out of ten when the circuit-breaker blows it ought not to blow. If you put a fuse in in place of the circuit-breaker you would not blow so often. So that it simmers down to the question of expense of renewing the fuses. If that could be got down cheap enough, I would prefer them to the circuit-breakers.

Another thing you brought up that I noticed was your suggestion of shunting switches to take the arc off. I think that would be considerable of a nuisance.

That brings us to another fact that I would like to state. I have gone on record several times as stating that the open fuse was a relic of the past, and I think also that the ordinary double-pole knife-switch is another and is not going to last. If switches were built properly there would be no need of shunting them with a fuse, and switches are going to be built properly so that they will not only act as switches, but also as circuit-openers, so that they can be quickly opened and closed, no matter whether the current is on or not. That is the thing we have got to have and will have.

MR. SACHS:—I think our chairman is quite familiar with the fuse qestion, and I think he ought to say something either pro or con.

THE CHAIRMAN:—I will say something in regard to what Mr. Cutler has said here, which might indicate to people who do not know me that I did not appreciate the advantages of a good fuse. In the first place, I have always been strongly in favor of the fuse, and most strongly opposed to the use of circuit-breakers in places where fuses should be used. This applies most commonly to the use of circuit-breakers on incandescent circuits. One example is enough. The other day in going over a plant which was originally designed by other people, but which we are at present completing, I found that they had circuit-breakers controlling the generators on an ordinary lighting circuit, and that the circuit-breaker would go out before it would blow a sixty-light fuse, the circuit-breaker being put in to protect a direct-current hundred-kilowatt machine. I think that one illustration is enough to show the foolishness of this indiscriminate use of circuit-breakers, due to the eloquence of the gentlemen who are selling them.

In regard to my seeming indifference to the enclosed fuse, I will say that that was probably due to the feeble efforts of the salesman. This may be excused possibly by the fact that there was "nothing in it," as he has explained. Shortly after seeing the enclosed fuse, which, as the gentleman says, I approved in a general way, I set myself about to design a switchboard in a plant where this could be used. I don't mean to say that I was going to design a plant just to work this fuse in, but I had a place where they would go if they were all right. I found that the makers had a fuse which would do all right where it controlled but a small amount of energy, *i. e.*, for a low-voltage, small current which was already cared for pretty well by the Edison plug, (which was approved by the underwriters.) but I found when it came to getting anything for higher potentials and large currents, that, in the first place, I couldn't get them at all: and, in the second place, there seemed to be no standard adopted; and, in the third place, I got very meager information as to what the people who were building these fuses could produce. So that possibly my trouble was not due to any deficiency of the salesmen, who probably had met these same difficulties, and therefore did not come back to me, but was due to the fact that this matter had not been taken up in the same scientific and thorough manner in which Mr. Sachs has taken it up. In other words, the enclosed fuse was not at that time developed; and I will say that the last attempt that I made to get a large fuse was a failure.

In laying out a plant it is necessary for an engineer to have at hand some practical data of sizes and dimensions. You can't lay out a switchboard and then trust to luck to find fuses to fit the switchboard and terminals. If you do, you will have to make the switchboard over, and there will be an extra expense for that. I think it is very safe to say that as soon as these fuses

are reduced to a standard they will immediately be adopted by the engineers for all cases which have been covered by the manufacturer.

In regard to Mr. Cutler's conclusion on switches I will say that I was very much interested in the ideas set forth on page 115 of using a fuse something like this to shunt a switch, because if it is possible to use a fuse that will handle voltages which Mr. Sachs says he can handle, it seems to be a satisfactory way of doing something which I have not yet seen done satisfactorily—that is, the breaking of circuits of very high potential. Any remarks about switches used for this purpose might be considered a criticism on the manufacturers and might be inopportune, as these switches are in the development stage. But I can see how this use of the fuse may be very desirable in certain cases, and I hope that Mr. Sachs will at some time in the future give us information that will enable us to know what we can do with these fuses.

In regard to the question that Mr. Cutler raised about opening circuits with switches I notice that the recent writers on this subject have drawn a distinction. I don't remember the exact wording, but I think it is between what they call "circuit-openers" and "current-openers"—that is, between a device which shall break the current and one which shall open the circuit. In a great many cases it is very desirable to have a device which will open the circuit when there is no current on, which can be done very cheaply. Where we have very high voltage feeders it becomes very expensive to go into the extremely complicated and costly switches for opening these circuits while carrying current, and ordinarily these circuits do not have to be opened with great frequency, and in many cases the ordinary switch is all right. The fuse such as has been described here, if used in very high voltage circuits, gives us a means of opening the circuits occasionally and under abnormal conditions when we are compelled to use a switch or some device as a current-opener.

MR. CUTLER:—I would like to say a few more words about the position which I took in not advocating the fuse for a switch. The greatest objection to it is that it is not "fool-proof." You can't get a man, after he has opened that switch once, to renew the fuse. That is the greatest point which manufacturers of electrical apparatus have to contend with—to make their appliances "fool-proof." You have got to make it not only so that it will work, but so that it is bound to work under any conditions.

I was reading an article to-night in which it was stated that the rule of writing correctly was to write in such a way, not that it could be understood, but so that it could not be misunderstood. That applies to making machinery. It is all right theoretically, of course; it stops the arcing.

Now, in regard to what I said about knife switches, it is not expensive to make knife switches properly; in fact, it is not as expensive as the way they make knife switches now. I allude to what is known as the clip type. It is very expensive to make a first-class clip switch. Switches that you buy have three or four clips on them, and they will touch on the edges of one or two and the others won't touch. To make a good one you have got to grind them to make a perfect contact. The ideal way to make a switch is to use laminated copper leaves and tip them with carbon, so that the laminated leaves leave before the carbon does. It is a very cheap switch to make. I have built thousands of them and I have never had one complaint, and you get no burning whatsoever on the copper contact. All the arcing is on the carbon. Now, you can open just as big a circuit, just as big a current with that sort of switch as you can with the circuit-breaker. That switch will not cost as much money to build as the switches that are on the market to-day.

There are those two objections then to putting a fuse across a switch, that it is not "fool-proof" and it is not necessary, and it saves no money, in my opinion.

THE CHAIRMAN:—I would like to say in regard to the use of switches for current-breaking that there is no discussion between Mr. Cutler and myself, because I take the same position. The ordinary switch is unsuitable for breaking current where the switches carry a large amount of energy. If we could get a switch that is made as good as the circuit-breaker and get it for less money, that is something we would be very glad to get, I am sure. I am glad to receive that information as well as what I have learned about the fuse.

I am strongly in favor of making everything "fool-proof," and I have struggled hard to spend money for that purpose in some cases, and I don't see that a fuse in connection with the switch would be of universal application. What I suggest is that it might be a very good thing in these special cases of extremely high voltages. These extremely high voltages are usually employed only in long-distance transmission from central stations, which central stations require the attendance of intelligent and experienced men; and while it is probably absolutely necessary to make an isolated plant "fool-proof" from one end to another as far as possible, to do that is practically impossible in a large central station, and there is a limit to what can be spent for installation. It is probably cheaper in a large station sometimes to pay for a little better grade of man than it is to pay for a very much higher grade of complicated apparatus.

MR. SACHS:—Mr. Chairman, I wish to answer Mr. Cutler's discussion of my paper, and I want to begin that answer with an almost complete exoneration of the underwriters.

I have had quite some experience with the underwriters, and have also been directly connected with one of the municipal

boards. Mr. Cutler has labored under a slight misconception—perhaps it would be better to say he has applied a misnomer to the board that acted upon the matter of motor protection in New York, where I resided up to about a year ago.

MR. CUTLER:—That is right; it was not the underwriters.

MR. SACHS:—It was not the underwriters by any means. In fact, the underwriters were entirely rational in the matter. But it was the Municipal Inspection Board that made this peculiar ruling. The underwriters by no means wanted a circuit-breaker installed with every motor.

I wish to explain to Mr. Cutler the difference between a solid-packed enclosed fuse and an air chamber fuse. I have named my fuse generally the solid-packed fuse in the course of the paper, which Mr. Cutler only saw this evening, and hence has not fully perused, or he might know that I speak of two types of solid-packed fuses. The mere packing of a tube and the throwing into that tube of chalk or sand or flue dust or anything that you can lay your hands on does not make an enclosed fuse that is accurate or safe, and such an enclosed fuse has the peculiar characteristics that Mr. Cutler mentioned, namely, that it is not accurate and it is not safe, for the simple reason as mentioned on page 95 and again at the bottom of page 98. Mr. Cutler will find on page 95, for instance, the record of a test of an "X" solid-packed fuse. This is a fuse with chalk thrown into the tube. Such a fuse as this, with the wire in a molten condition, is absolutely inaccurate. And he will also find by continuing on in the paper that it fully discusses the matter of surrounding the wire with a material that eliminates this peculiar hanging, and this material requires the most careful selection, but by the use of such material, which completely surrounds the fuse wire and fills the casing between the wire and the sides of the casing completely, we also obtain a vast multitude of advantages over the air chamber fuse.

In the first place it must be remembered that any fuse surrounded by air always retains some of the disadvantages of an air-surrounded fuse as far as accuracy is concerned, although to a very great extent it may be practically safe.

The detrimental results of oxide formations around the air-surrounded fuse wire in either case greatly affect the operative accuracy of the device in time. Aside from this feature, the absorption of at least some, if not all, of the gases of disruption in forming a combination with the filling is unquestionably capable of better results than when these gases can only be destroyed by parting with their heat in passing through the interstices of the filling. The amount of metal dissipated is also an important item. These points are fully discussed in the paper.

The fuse that I have devised is a solid-packed fuse, which type, I claim, is superior to any other, as it contains the minimum amount of air, it absorbs some of this disruptive energy—I don't say all, but some—it is absolutely accurate and cannot fail to

operate when overloaded. Owing to the fluxing action of the filling on the wire surface it is impossible for the fuse to continuously carry more current than it is designed for.

The matter of the indicating wire being in its action contrary to the name of the fuse, I beg most strongly to take exception to, for the simple reason that, as I have shown you, the indicating wire does not arc, it is simply melted, the break being really shunted by the final interior break. To prove this I will try the experiment previously mentioned.

[Mr. Sachs here placed dry cotton waste upon an enclosed fuse and blew it without setting fire to the waste.]

Perhaps that will satisfy Mr. Cutler. Mr. Cutler must remember that an arc and a mere melting are two different things. What we are getting there is really a melting of the indicator with perhaps a slight spark. I seriously doubt that there is any material, except gunpowder, or perhaps acetylene, illuminating or other highly inflammable gas, that if brought in direct contact with that little spark would actually be ignited by it. But, aside from that, it is true that the fuse has an indicator, but if Mr. Cutler finds this feature undesirable, it can be gotten rid of very easily. All you have got to do is to take your penknife and cut it off. Now, if Mr. Cutler would rather use fuses without indicators, he is entitled to do so. But I shall not charge any more for the fuse with or without an indicator. I am a firm believer in the precept that you should always know what you are about before going ahead. You can't go ahead until you know whether your fuse has blown or not. If you have an indicator to show that it has blown, all guesswork and risk is eliminated. We have had a number of cases brought to our attention in which the enclosed fuses were to blame for serious results, simply because they had no means of notifying the user when they were disrupted.

In the matter of fuses on switchboards in place of circuit-breakers, I agree with Mr. Cutler most heartily; and the use of a fuse that can be thrown into the circuit as quickly as a circuit-breaker is an entirely reasonable device. I have a fuse of this type under consideration, consisting of a magazine fuse device that can be mounted upon a switchboard with a handle to project the same as a rheostat handle projects. All that is necessary is to turn the handle. The turning of the handle can even be performed automatically when the fuse is used as a circuit-breaker.

In regard to shunting switch breaks on medium or high-potential circuits, I think the view taken by Mr. Pierce is entirely the correct one. You don't have to shunt a break on a 220-volt switch, and perhaps you don't have to shunt a break on a 500-volt switch; but when it comes to breaking currents on 2500 volts or above, why, it becomes necessary to provide some medium to eliminate arcing, because even the slightest tendency to

create a conducting medium between your breaking points starts an arc which under these potentials is severely destructive. In the fuse-shunted breaks the starting of an arc at the switch is eliminated. I, by no means, recommend such a device for use where the switches are opened and closed many times an hour—it would be rather an expensive switch to use; one for which you would pay 12 cents, 15 or 20 cents or more than that every time you opened it. For the satisfactory operation of this arrangement it necessarily follows that every time you open the switch there is load enough on it to blow the fuse, which has a much smaller capacity than the switch, and the placing of a new switch must be assured.

On the "fool-proof" question, I must say that I also take exactly Mr. Pierce's view. You can't build a thing absolutely "fool-proof," and when you are putting in thousands and thousands of dollars worth of machinery, certainly you should not put a dollar-and-a-half-a-day man in charge of it. When you find that your three-dollar-a-day man hasn't got brains enough to operate the switch properly you get rid of the man and not the switch.

I stand ready to-day to say that an enclosed switch fuse of this character can be produced to rupture almost any excess-current condition. It is surely a question of a proper combination of wire and casing and filling. Certainly when you get enormous potentials or enormous current capacities, your fuse may perhaps be abnormally large, but the circuit can be ruptured without arcing if the fuse is properly constructed. I have built fuses large enough to demonstrate that. In fact, have opened a short-circuit on one of the largest street railway systems in the world, the fuse having a normal current-carrying capacity continuously of about 500 K.W., which is by no means small.

I think that owing to the fact that this paper was probably not in the hands of a great many present, and as Mr. Cutler only received it to-night that it has made it a little difficult probably for him to discuss it as fully as he would like; and as we all appreciate that written communications are in order, I think that any further discussion might be conducted in writing:

[Adjourned.]

Books Received by the Institute.

Modern Electric Railway Motors, a Discussion of Current Practice in Electric Railway Motor Construction, Maintenance, and Repair, by Geo. T. Hanchett, M. A. I. E. E. *Street Railway Publishing Co.*, New York, 200 pp. 6¼ x 9 in., 157 cuts.

The object of this book is to show how electric railway motors are made today and why they are made so. It is intended more particularly for those who have just entered or about to enter active work in the electric railway field While the book is largely of a descriptive character, a few general principles are laid down illustrated by past and present practice and comparisons of merit. There is a chapter on the management and repair, and another on the design of motors. The following are the chapter headings.

Forms of Field Magnets; Armature Winding Diagrams; Field Coil Construction and Arrangement; Armature Construction; Commutators and Brush holders; Motor Casings; Motor Suspensions; Bearings and Gears; Lubrication; General Data and Dimensions; Management and Repairs; The Design of a Street Railway Motor.

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